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# FIREFIGHTING EFFECTIVENESS OF AQUEOUS-FILM-FORMING-FOAM (AFFF) AGENTS

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13. ABSTRACT

Information was obtained by conducting laboratory experiments and full-scale fire-modeling tests which were of value in estimating the firefighting effectiveness of two aqueous-film-forming-foam (AFFF) agents. Minimum quantities and application rates were established for each AFFF agent in relation to the size and configuration of simulated aircraft ground fuel-spill fires involving JP-4, JP-5 and aviation gasoline.

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| Suppression Equipment | | | | | | |
| Suppression of Aircraft Fires | | | | | | |
| Fire Extinguishers | | | | | | |



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## FOREWORD

This final technical report describes the results of laboratory experiments and full-scale fire-modeling tests concerned in an evaluation of the firefighting effectiveness of two new foam agents and dispensing equipment. This program was conducted under Contract No. F33615-71-M-5004 for the Tri-Service Aircraft Ground Fire Suppression and Rescue (AGFSR) Office, Wright-Patterson Air Force Base, Ohio, by the Propulsion and Fire Protection Branch, Aircraft Safety Division, National Aviation Facilities Experimental Center, Atlantic City, New Jersey under Project No. 910-003-62X. The program was conducted during the period of 1 January 1971 to 29 February 1972.

Mr. Niles J. Fisher was program monitor for the Tri-Service Aircraft Ground Fire Suppression and Rescue Office.

## PUBLICATION REVIEW

This document was originally submitted in draft form by the author in July 1972 and in final form in May 1973. It is published to reflect the data obtained by the author from laboratory and full-scale experiments. This technical report has been reviewed and is approved.

Robert B. Artz

ROBERT B. ARTZ, LT COL., USAF
CHIEF, Acft Gnd Fire Suppression
and Rescue Office
Directorate of Specialized Subsystems

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## INTRODUCTION

### Objective.

The project objective was to establish the firefighting capabilities of newly-developed aqueous-film-forming-foam (AFFF) agents and to determine their potential value, where applicable, in aircraft ground fire suppression and rescue systems.

### Background.

The operation of advanced military and commercial aircraft establishes a requirement for improved firefighting capabilities which can effectively control hazards associated with new types and increased quantities of fuels. Therefore, the technology of fire suppression must advance equally to meet the problems of these increasing hazards. This required a program to investigate newly-developed firefighting foam agents and utilization techniques in an effort to determine those which best meet current and future demands.

The problems associated with the extinguishment of aircraft fuel fires involve chemistry, the physical characteristics of interfaces, and related mechanical requirements. The most commonly employed fire extinguishing agent in aircraft firefighting is water and its principal modification, foam. The most recent developments in this area utilize perfluorinated hydrocarbon surfactants (Reference 1) which modify the physical characteristics of water to combine the properties of foam with certain significant interfacial activities between the fuel and water which contribute to its overall effectiveness. The practical problems of fire protection using these materials in fire protection systems are being solved by continued development of these new materials and field testing.

### Scope.

The scope of the project included an evaluation of the fire suppression, fire containment, and foam characteristics of two commercially available AFFF agents designated as Manufacturer A and Manufacturer B in this document. The physical properties and firefighting performance of protein foam (Manufacturer C) are included for comparison with the AFFF agents where applicable. One experimental AFFF (Manufacturer D) became available during the course of the project and was evaluated in some of the laboratory experiments along with the other two AFFF agents.

## DISCUSSION

### Test Procedures.

Laboratory Evaluation of Foam Agents. A selected series of laboratory experiments was performed which were considered significant with regard to the technical and practical application of AFFF and protein foam in aircraft ground-firefighting systems and operations. These experiments were in addition to those contained in the Federal Specification (Reference 2) for protein foam and in the Military Specification (Reference 3) for the AFFF agents.

The physical characteristics and fire-test performance of each foam agent evaluated in accordance with the pertinent federal or military specification were supplied by the respective agent manufacturer and are presented in Table 1.

Compatibility of AFFF and Protein Foam Liquid Concentrates. The probability that AFFF and protein foams will be used concurrently in airfield firefighting operations is increasing and required that tests be performed to determine the effect upon the resulting solution if these agents are inadvertently mixed. Accelerated aging tests were therefore performed to determine the degree of compatibility between mixtures of the AFFF agents and protein foam liquid concentrates when tested in accordance with the Federal Specification (Reference 2) under Requirements 3.3 Compatibility as specified in 4.7.7.2 high-temperature stability 149°F (65°C). The foam expansion ratio and 25 percent solution drainage time was also determined with a kitchen mixer in accordance with the test procedure outlined in Appendix A, but omitting the dry-chemical powder and test fuel. The results of these experiments are presented in Table 2.

The high-temperature stability test procedure (Reference 2) requires that the sedimentation value not be greater than 0.25 percent by volume and that it shall be completely dispersible on mild shaking. Table 2 shows that only one combination of the three foam liquid concentrates tested yielded a sediment in excess of this maximum. The critical combination of AFFF liquids was 50 percent of Manufacturer A's product to 50 percent of Manufacturer B's product. A borderline condition appears to maintain when 75 percent of Manufacturer B's agent is mixed with 25 percent of Manufacturer A's agent.

It is also noteworthy that foam quality expressed in terms of the 25-percent solution drainage time and expansion ratio was lowest when the ratio of Manufacturer A's liquid to Manufacturer B's liquid was 75:25 and not in the 50:50 mixture where the sediment was higher.

TABLE 1. PHYSICAL PROPERTIES OF THE FOAM LIQUID CONCENTRATES

| | AFFF Agents | | Protein Foam (Reference 2) |
|---|---|---|---|
| Physical Properties | Manufacturer A | Manufacturer B | Manufacturer C |
| Specific Gravity | 1.037@ 77°F | 1.029@ 60°F | 1.143@ 60°F |
| Viscosity C.S. | 13.4@ 40°F | 11.35@ 40°F | 56.22@ 40°F |
| PH Value | 4.6@ 77°F | 8.1 | 7.4@ 70°F |
| Surface Tension dynes/cm | 16 77°F | 18 | NA* |
| Interfacial Tension dynes/cm | 2.7 77°F | 2.5 | NA |
| Chloride ppm | 2 | - | NA |
| 2GPM Foamability @70°F cc/gm | | | |
| Sea Water | 8.8 | 7.75 | NA |
| Fresh Water | 9.4 | 7.5 | NA |
| 25% Drainage Time @70°F min. | | | |
| Sea Water | 3.6 | 5.27 | (Meets Requirements of Federal Specification) |
| Fresh Water | 4.5 | 4.5 | |
| Film Sealability @70°F | | | |
| Sea Water | Satisfactory | Satisfactory | NA |
| Fresh Water | Satisfactory | Satisfactory | NA |
| $28ft^2$ Fire Test | | | |
| Sea Water | | | |
| 25% Burn Back min. | 4.3 | Not Performed | NA |
| Application Density for Extinguishing $gal/ft^2$ | 0.039 | Not Performed | NA (Meets Requirements of Federal Specification) |
| Fresh Water | | | |
| 25% Burn Back min. | 4.9 | Satisfactory | NA |
| Application Density for Extinguishing $gal/ft^2$ | 0.027 | 0.05 | NA |
| $400ft^2$ Fire Test | | | |
| Sea Water | | | |
| 30sec % Extinguish. | 93 | Not Performed | NA |
| 40sec % Summation | 351 | Not Performed | NA |

*NA - Not Applicable

TABLE 2. COMPATIBILITY OF AFFF AND PROTEIN FOAM LIQUID CONCENTRATES IN ACCELERATED AGING TESTS

| Foam Agent | | | | | |
|---|---|---|---|---|---|
| Foam Liquid Mixtures (Percent by Volume) | | | | | |
| Manufacturer A | 0 | 25 | 50 | 75 | 100 |
| Manufacturer B | 100 | 75 | 50 | 25 | 0 |
| Percent Sediment | 0.10 | 0.25 | 1.00 | 0.20 | 0.10 |
| Foam Expansion Ratio | 23.2 | 25 | 23.3 | 13.4 | 22.9 |
| Drainage Time (25 Percent) min:sec | 8:47 | 7:00 | 5:50 | 2:58 | 7:08 |
| Manufacturer A | 0 | 25 | 50 | 75 | 100 |
| Protein Foam | 100 | 75 | 50 | 25 | 0 |
| Percent Sediment | 0.05 | 0.05 | 0.05 | 0.15 | 0.10 |
| Foam Expansion Ratio | 12.1 | 19.4 | 17.3 | 15.5 | 22.9 |
| Drainage Time (25 Percent) min:sec | 28:24 | 8:55 | 4:58 | 5:26 | 7:08 |
| Manufacturer B | 0 | 25 | 50 | 75 | 100 |
| Protein Foam | 100 | 75 | 50 | 25 | 0 |
| Percent Sediment | 0.05 | 0.05 | 0.12 | 0.12 | 0.10 |
| Foam Expansion Ratio | 12.1 | 16.8 | 20.6 | 19.1 | 23.2 |
| Drainage Time (25 Percent) min:sec | 28:24 | 4:22 | 4:56 | 4:55 | 8:47 |

Mixtures of the two different AFFF agents with the protein foam liquid showed relatively minor overall variations in the sedimentation values and foam quality.

When considering the stability and foam quality characteristics of mixed solutions of protein foams and the AFFF agents, it is noteworthy that a class of foam agents is available which may be considered to lie between the true protein foams and the AFFF agents in terms of their chemical composition. These agents have been designated as the fluoroprotein foams (Reference 4) and were developed by the Naval Applied Science Laboratory in a joint effort with industry to achieve an acceptable degree of compatibility between protein-type foams and Purple-K Powder (PKP) (Reference 5). Other fluoroprotein foams are currently available which are claimed by their manufacturers to provide the firefighting effectiveness and film-forming properties of AFFF.

Stability of AFFF on Polar Solvent Fires. The polar solvent most frequently used onboard aircraft is methanol, either neat or in the form of its aqueous solutions. The quantity of neat methanol carried may vary from a few gallons (gal) to 45 gal or more depending upon the configuration of the aircraft. Therefore, experiments were performed with neat methanol and its aqueous solutions in accordance with the experimental requirements in Appendix B.

The results of the foam stability tests using foam produced by the AFFF agents and protein foam on four different concentrations of methanol are presented in Table 3. These data indicate that the rate of decomposition of the three foams in contact with methanol decreased as the solution became more dilute and that the critical (minimum dilution) concentration lies between 50 and 75 percent by volume.

Another potential hazard associated with the presence of neat methanol onboard an aircraft is the possibility of its being spilled and mixed with any hydrocarbon aircraft engine fuel on the ground. Therefore, it was necessary to assess the fuel vapor-securing and blanketing effectiveness of the AFFF agents on mixtures of methanol and three common aircraft fuels; i.e., JP-4, Jet A, and aviation gas (avgas).

To determine the stability of the foam produced by the AFFF agents on methanol/fuel mixtures, a series of experiments was conducted in accordance with the test procedure in Appendix B, with the exception that 1-percent and 20-percent mixtures of methanol were made with each aircraft fuel and substituted for the aqueous methanol solutions. As a consequence of the greater stability of the AFFF blankets on methanol/fuel mixtures over aqueous solutions of methanol, the foam blanket observation period was extended to 60 minutes.

TABLE 3. STABILITY OF AFFF AND PROTEIN FOAMS ON NEAT METHANOL AND ITS AQUEOUS SOLUTIONS

| Polar Solvent Methanol Concentration Percent | Foam Stability Time min:sec AFFF Manufacturer A | Manufacturer B | Protein Foam (Reference 2) Manufacturer C |
|---|---|---|---|
| 100 | 0:08 | 0:08 | 0:08 |
| 75 | 2:20 | 0:42 | 19:45 |
| 50 | 17:23 | 30:00 | 30:00 |
| 25 | 30:00 | 30:00 | 30:00 |
| 0 | 30:00 | 30:00 | 30:00 |

To test the vapor-securing property of the aqueous fluorocarbon foam during the course of each experiment, a small lighted torch was passed over the surface of the foam at 10-minute intervals. In all experiments the torching ultimately produced a transient flash of fire which was self-extinguishing, and no permanent ignition of the alcohol/fuel mixture resulted even though in some experiments there was little or no foam present. From this series of experiments it was evident that the stability of AFFF on the surface of methanol/fuel mixtures was a function of the agent, the type of hydrocarbon fuel, and the methanol concentration in the fuel.

In general the stability of AFFF decreased when placed on the surface of methanol/fuel mixtures as the alcohol concentration increased from 1 to 20 percent by volume. The effect of the hydrocarbon component in the methanol/fuel mixtures was to decrease the AFFF stability as the fuel was changed from Jet A, JP-4, and avgas. The results of these experiments are summarized in Table 4 where the data are based upon the times required for sustained ignition to occur after torching the foam.

TABLE 4. STABILITY OF AFF ON MIXTURES OF METHANOL AND THREE DIFFERENT AIRCRAFT FUELS

ESTIMATED FOAM STABILITY TIME-MINUTES

| Methanol/JP-4 Concentrations | 1 Percent | 20 Percent |
|---|---|---|
| Manufacturer A | 50-60 | 40-50 |
| Manufacturer B | 30-40 | 20-30 |
| **Methanol/Avgas Concentrations** | | |
| Manufacturer A | 25-30 | 15-25 |
| Manufacturer B | 7-10 | 3-7 |
| **Methanol/Jet A Concentrations** | | |
| Manufacturer A | over 60 | over 60 |
| Manufacturer B | over 60 | over 60 |

Compatibility of AFFF With Dry-Chemical Powders. The firefighting performance of all dry-chemical powders may be regarded to be of the "go" or "no-go" type. That is, the fire is either completely extinguished and the environment allowed to cool below the flash point of the fuel, or the fire will reflash. Therefore, their principal use in combatting complex three-dimensional fuel-spill fires is as auxiliary or complimentary agents in conjunction with one or more of the foam-blanketing agents.

The increasing use of dry-chemical powders as auxiliary agents in aircraft accidents requires a knowledge of the compatibility of these agents with different foams. The results of large-scale fire tests performed at the National Aviation Facilities Experimental Center (NAFEC), Reference 6, with incompatible powder-foam combinations resulted in an almost complete cancellation of the firefighting effectiveness of both agents, and fire control was never obtained. To be successful the dry-chemical powders used in either a combined agent attack or as mop-up agents should demonstrate a reasonable degree of compatibility with the foam.

The compatibility between dry-chemical powders and different foams is usually one of degree rather than an absolute value. Therefore, laboratory tests designed to evaluate this property must be correlated with the results obtained using the same agents under actual full-scale crash fire conditions. The laboratory test outlined in Appendix C contains the four parameters existent in all aircraft fire situations in which foam and powder are employed; i.e., fuel, heat, foam, and dry-chemical powder. The purpose of employing this test procedure, in which the materials are intimately mixed and exposed to intense thermal radiation, was to attempt to simulate the most severe conditions which might be realized under actual crash firefighting conditions to avoid the ambiguity sometimes associated with interpreting the results of tests representative of some unknown intermediate degree of fire severity.

The results of experiments performed in accordance with this procedure using a variety of foam and dry-chemical agents indicated that if the time required to collect 25 milliliters (ml) of foam solution was 2.0 minutes (min) or more, an acceptable degree of compatibility would be obtained under conditions involving a high-degree of turbulence of the burning fuel, foam, and dry-chemical powder in crash-fire situations.

The results obtained using the procedure contained in Appendix C and three different AFFF agents (Manufacturers A, B, and D) are presented in Table 5. Agent D was a new experimental candidate AFFF that became available during the time these experiments were in progress and was included in the program to augment the labororatory foam/powder compatibility performance data.

A comparison of the 25-percent foam solution drainage times presented in Table 5 shows that the drainage time was less for all of the different combinations of powder, foam, and fuel than it was in the absence of powder under equivalent experimental conditions.

TABLE 5. COMPATIBILITY OF AFFF WITH DRY-CHEMICAL POWDERS AND THREE DIFFERENT AIRCRAFT FUELS

FOAM STABILITY
min:sec

Fuel JP-4

| AFFF Agents | Super K | PKP | CDC | No Powder |
|---|---|---|---|---|
| **Fuel JP-4** | | | | |
| Manufacturer A | 2:57 | 2:05 | 2:13 | 9:13 |
| ~~Manufacturer B~~ | ~~3:04~~ | 0:30 | 6:09 | 9:42 |
| Manufacturer D | 4:25 | 2:40 | 4:26 | 9:47 |
| **Fuel JP-5** | | | | |
| Manufacturer A | 2:37 | 2:22 | 2:10 | 7:31 |
| Manufacturer B | 2:08 | 2:16 | 3:39 | 5:13 |
| Manufacturer D | 3:31 | 2:42 | 3:26 | 8:40 |
| **Fuel Avgas (140 Octane)** | | | | |
| Manufacturer A | 4:37 | 1:32 | 2:15 | 9:36 |
| Manufacturer B | 4:55 | 0:05 | 4:50 | 9:50 |
| Manufacturer D | 5:20 | 1:45 | 4:34 | 10:49 |

The test data indicate that Super K, a potassium chloride base powder, and compatible dry chemical (CDC) (Reference 7), a sodium bicarbonate base powder, produced the most consistent compatibility performance with the three AFFF agents and aviation fuels. The compatibility shown by PKP, a potassium bicarbonate base powder, varied with the AFFF agent used and was a function of the type of fuel employed in each experiment.

The foam solution drainage times presented in Table 5, which show Manufacturer B's agent used with PKP and JP-4 fuel and Manufacturer A's, B's and D's agents with PKP and avgas, are all below the minimum 2-min-25-percent drainage time established for compatibility under the most severe fire conditions. These data do not necessarily imply, however, that these combinations of agents and fuels should never be employed in firefighting operations, but they do indicate that care should be exercised when applying foam on the fire to avoid direct plunging insofar as possible.

These experiments are considered significant in that they serve to confirm and emphasize the fact that the compatibility between powder, foam, and fuel is one of degree under conditions of severe turbulation and therefore is worthy of consideration when establishing full-scale firefighting procedures and training techniques.

Full-Scale Fire-Modeling Experiments.

Fire Test Facility and Test Methods. The fire test bed comprised a 200-foot diameter fire pit with a soil-cement base covered by a 12-inch layer of clayey soil. A 6-inch-thick layer of 3/4-inch traprock overlaid this surface to present a rough texture and more severe fire conditions than those obtained under simple water-base pool fire conditions. Within this area concentric pools were constructed which varied from 46 to 125 feet in diameter. By removing the interventing dikes it was possible to change from one pool size to the next larger.

An obstacle comprising a cruciform configuration of six 55-gallon steel drums and a three-dimensional fire was provided in the center of the fire pool to act as an ignition source for the burnback tests. The three-dimensional fire was sustained by directing a solid stream of fuel from a height of 4 feet into a 2-foot-square pan with 2-inch-high sides placed on the ground downwind of the drums as shown in Figure 1. Uniform environmental burning conditions were maintained by allowing a 30-second preburn time at maximum radiation intensity which was determined from the radiometer data before foam application was started (Appendix D).

A burnback test was conducted as part of each experiment by measuring the time required for the unextinguished three-dimensional fire to progressively increase in size until a radiation intensity of 0.5 Btu-per-square-foot per second (ft/sec) was detected by any one of the four radiometers located around the pool perimeter. The radiometer distribution is presented schematically in Figure 2. Heat sensors A and B were elevated on steel poles 8 feet above ground level on the diameter at right angles to the wind direction and remained in position throughout the test. Radiometers C and D were 42 inches high and placed on the downwind side of the pool after fire control had been obtained to monitor the increase in heat flux during the burnback cycle. Thermal data were recorded on two instruments equipped with event markers.

A description of the instrumentation employed to monitor the full-scale fire-modeling experiments is contained in Appendix E.

Photographic coverage of each fire test was provided in accordance with the procedure presented in Appendix F.

Foam Nozzles. Two different air-aspirating foam nozzles were employed in the experiments. One (Nozzle A) was a single barrel unit with a nominal solution discharge rate of 250 gallons per minute (gal/min). This nozzle was capable of imparting high energy to the foam stream by creating a condition of turbulation and shear to the foam during its passage

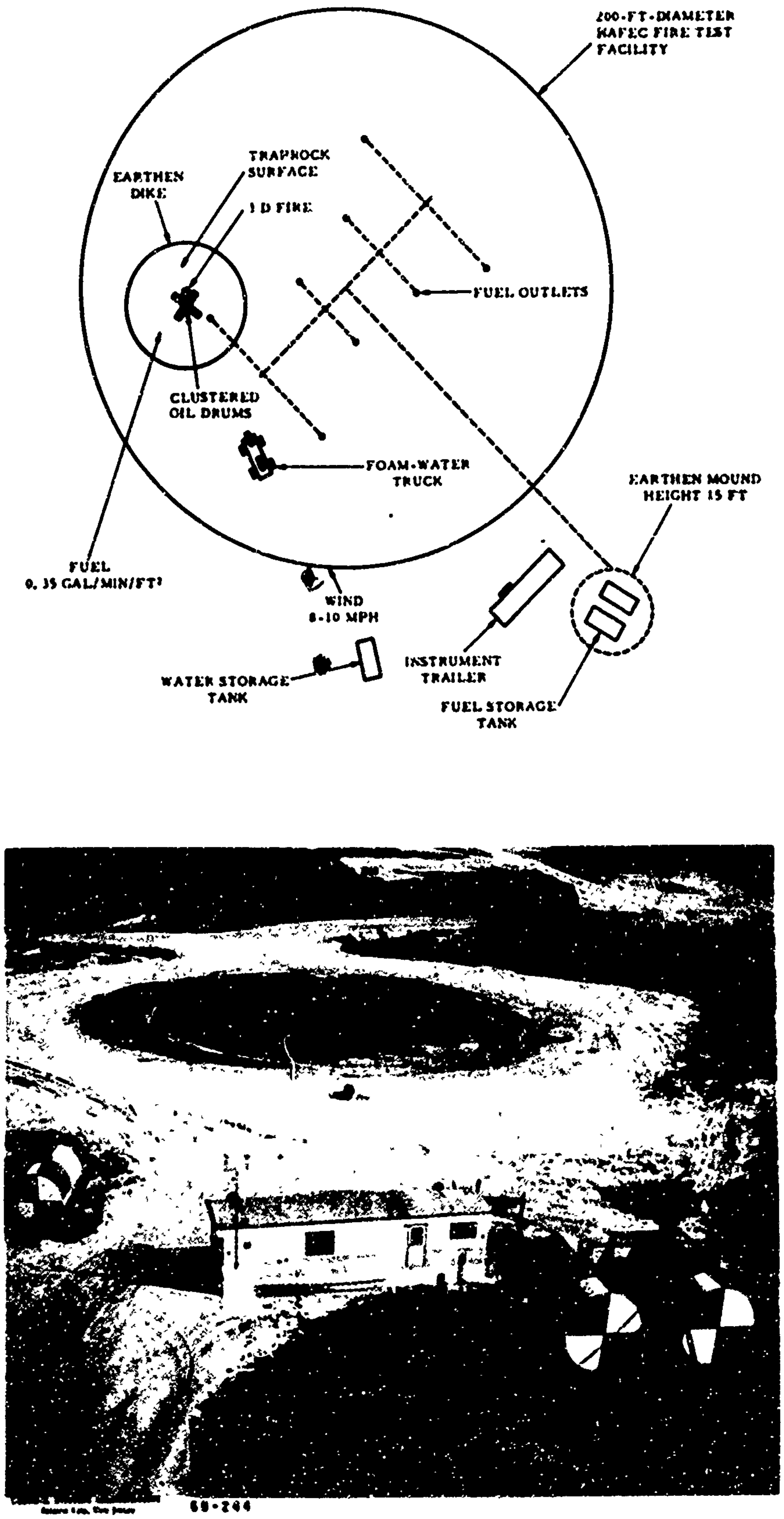


FIGURE 1. SCHEMATIC AND PICTORIAL PRESENTATION OF THE FIRE TEST FACILITY

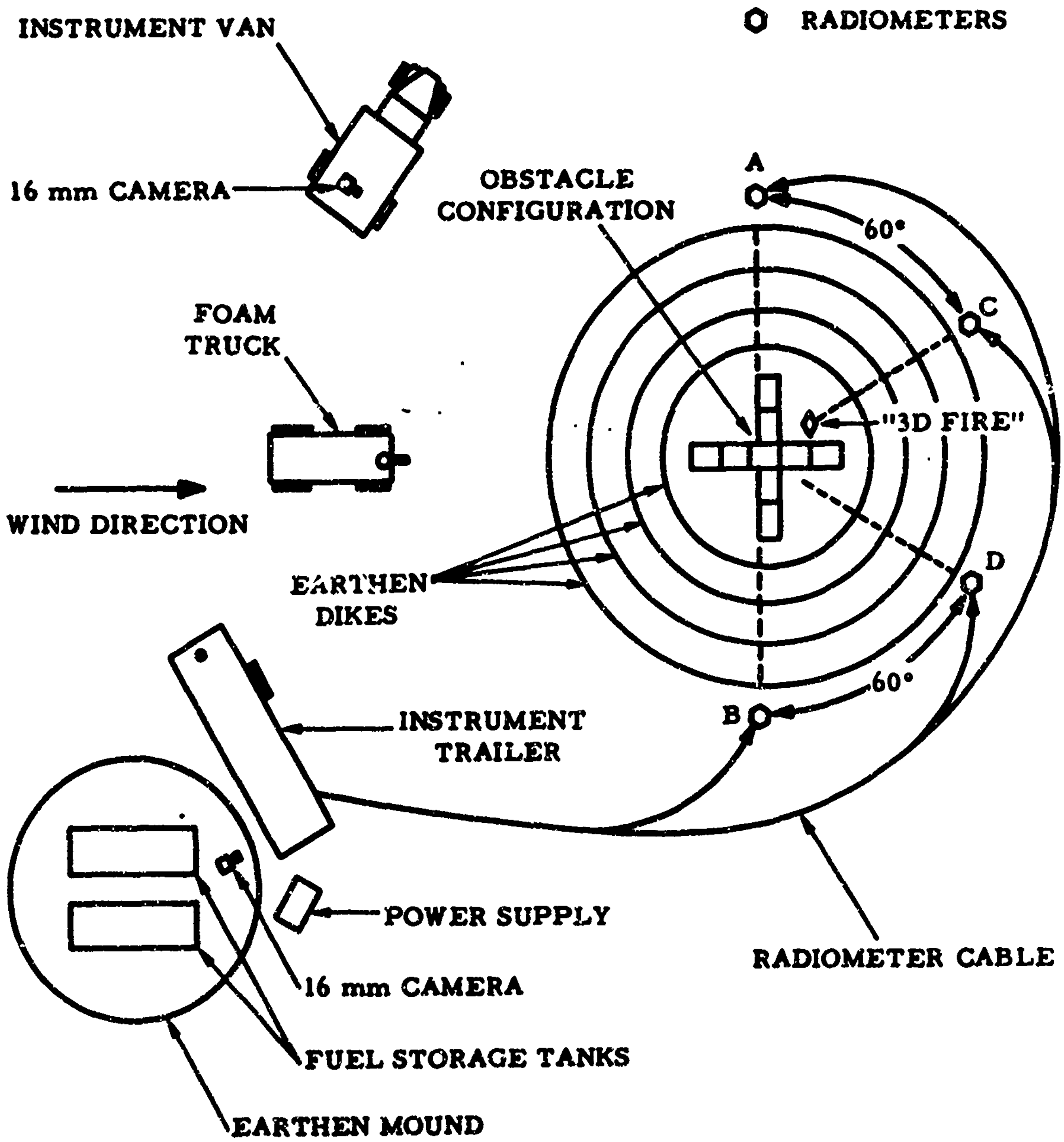


FIGURE 2. PLAN VIEW OF THE FIRE TEST BED SHOWING THE RADIOMETER AND CAMERA LOCATIONS

through the barrel. Foam shapers at the mouth of the barrel were capable of changing the foam pattern from straight stream to the fully dispersed pattern in a continuous manner. The straight stream foam discharge pattern was approximately 165 feet long and 16 feet wide while the fully dispersed pattern was approximately 58 feet long and 46 feet wide when the foam shapers were open approximately five-eights-inch at the tips.

Photographs of Foam Nozzle A and diagrams of the foam patterns produced by the straight and fully dispersed streams are presented in Figure 3.

The second air-aspirating foam nozzle (Nozzle B) was a composite unit consisting of two 400-gal/min foam-dispensing units and two 400-gal/min water discharge nozzles. The AFFF and water-dispensing systems were arranged so that in both systems the nozzles could be discharged either singly or in combination. The straight stream foam discharge pattern using one 400-gal/min barrel was approximately 121 feet long and approximately 21 feet wide. With two 400-gal/min barrels operating simultaneously, the straight stream foam pattern was approximately 124 feet long and 24 feet wide. The fully dispersed foam pattern produced by one 400-gal/min barrel was approximately 85 feet long and 33 feet wide. When both 400-gal/min barrels were discharged simultaneously using the fully dispersed stream, the foam pattern was approximately 86 feet long and 40 feet wide.

Photographs showing the general configuration of Foam Nozzle B and diagrams of the foam patterns produced by the straight and dispersed streams are presented in Figure 4.

Foam Quality Determinations. The quality of expanded foams produced from liquids made by Manufacturer A and Manufacturer B were evaluated in terms of the foam expansion ratio, 25-percent solution drainage time and foam viscosity using Nozzle A and Nozzle B which were subsequently employed in the full-scale fire-modeling experiments. A solution concentration of 6 percent by volume was considered standard and employed in all foam quality determinations and fire tests.

The foam expansion ratio and the 25-percent solution drainage time was determined for the AFFF agents in accordance with procedures contained in Reference 8.

Foam viscosity was determined by employing the viscometer shown in Figure 5. Essentially, the instrument consists of a constant speed rotating torsion wire and vane which may be adjusted to shear a sample of foam held in a spherical container. The torsion wire and vane are rotated by a geared motor in the head of the instrument. The torsion wire is enclosed in a brass tube on the downward facing spindle of the gear box.

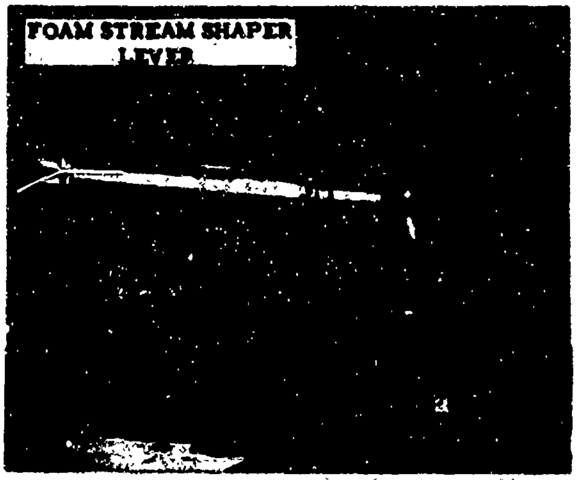


FIGURE 3-1. PROFILE VIEW

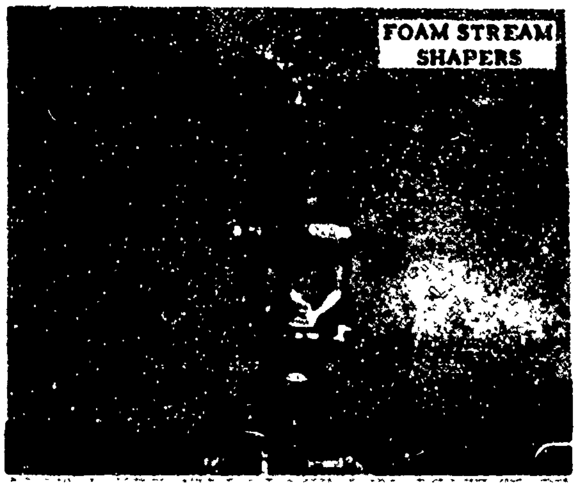


FIGURE 3-2. FRONT VIEW

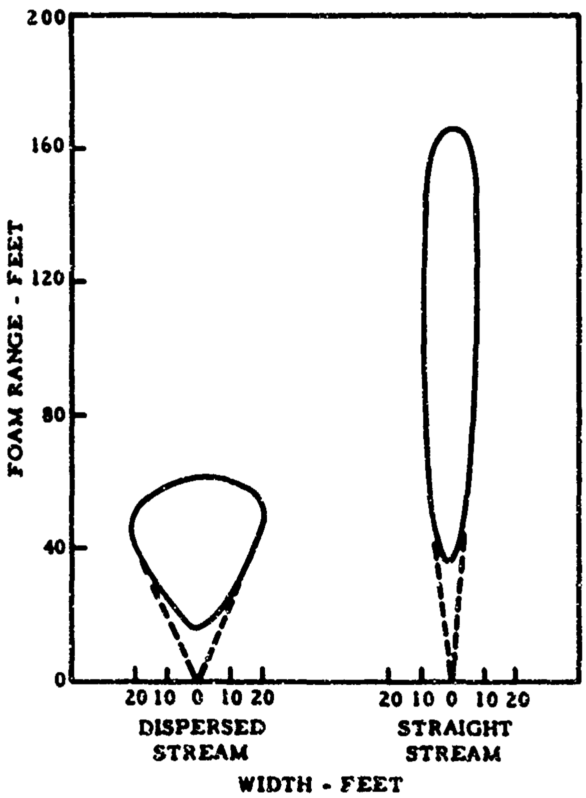


FIGURE 3-3. FOAM GROUND PATTERNS AT A SOLUTION RATE OF 250 GAL/MIN

FIGURE 3. GENERAL CONFIGURATION OF FOAM NOZZLE A AND THE FOAM GROUND PATTERNS PRODUCED WITH AFFF

FIGURE 4-1. PROFILE VIEW

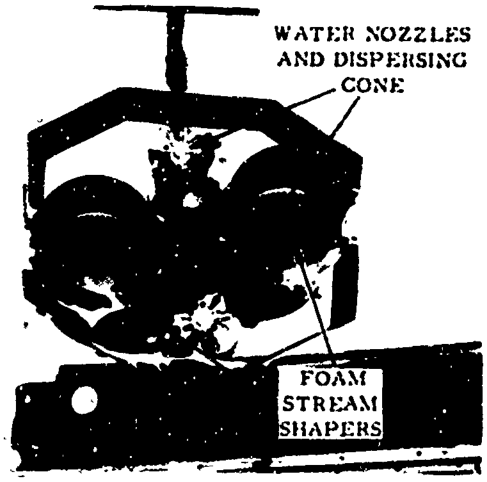


FIGURE 4-2. FRONT VIEW

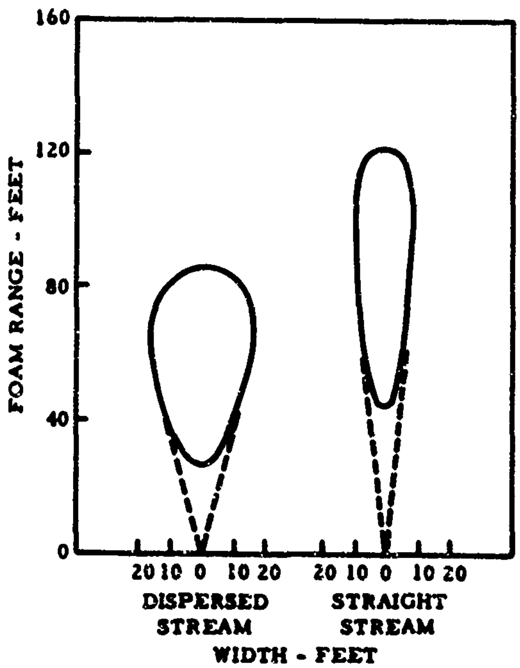


FIGURE 4-3. FOAM GROUND PATTERNS AT A SOLUTION RATE OF 400 GAL/MIN

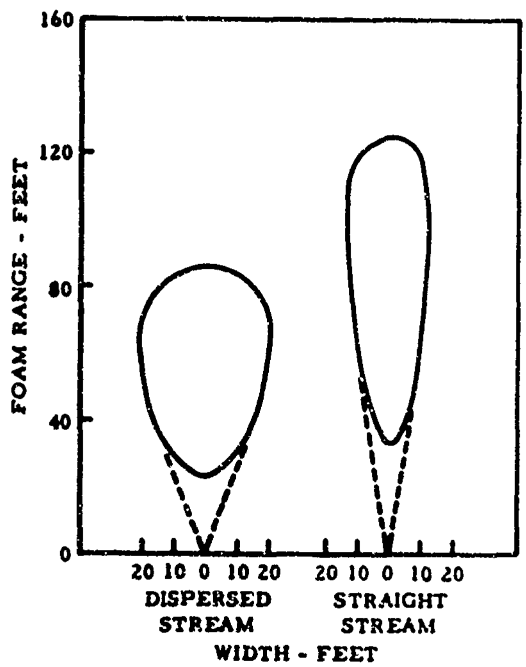


FIGURE 4-4. FOAM GROUND PATTERNS AT A SOLUTION RATE OF 800 GAL/MIN

FIGURE 4. GENERAL CONFIGURATION OF FOAM NOZZLE B AND THE FOAM GROUND PATTERNS PRODUCED WITH AFFF

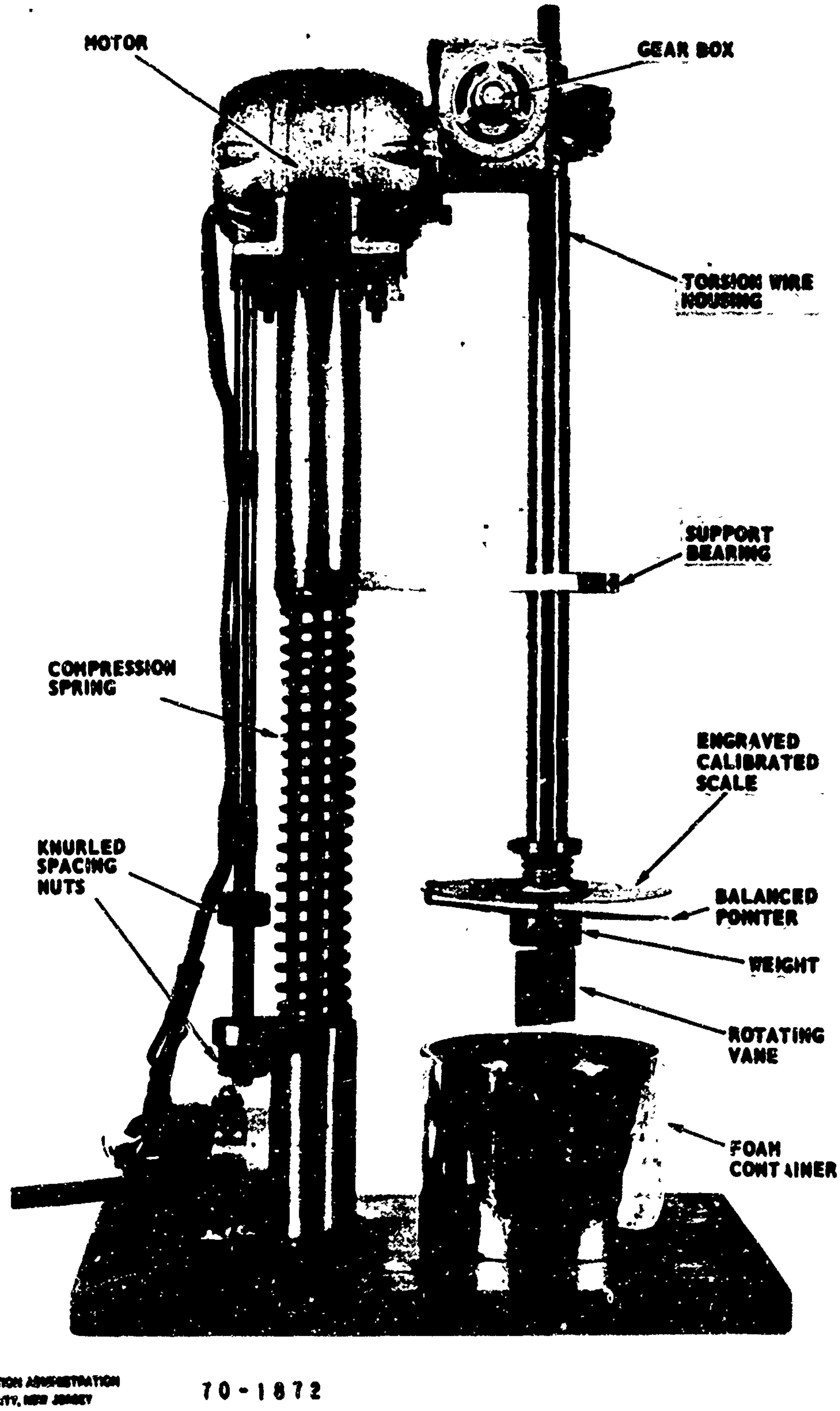


FIGURE 5. FOAM VISCOMETER

Attached to the lower end of this tube is an adjustable circular scale which is divided into 100 divisions. The vane is attached to the torsion wire which is also fitted with a steel disc of sufficient size to keep the wire taut. These components are arranged so that they can be moved vertically as a unit, and the sliding head is fitted with adjustable stops which can be present so that when the head is depressed the vane is fully emersed in the foam to its uppermost edge. The dimension of foam viscosity determined by this method is dynes per square centimeter (sq cm).

The results of the foam quality experiments are presented in Table 6.

TABLE 6. QUALITY OF FOAM PRODUCED BY THE AFFF AGENTS USING FOAM NOZZLE A AND NOZZLE B

| | Foam Solution Discharge Rate gal/min | | | | | |
|---|---|---|---|---|---|---|
| | AFFF Manufacturer A | | | AFFF Manufacturer B | | |
| | Nozzle A | Nozzle B | | Nozzle A | Nozzle B | |
| | 250 | 400 | 800 | 250 | 400 | 800 |
| Foam Viscosity dynes/sq.cm. | 65.0 | 75.4 | 82.88 | 82.9 | 94.7 | 106.1 |
| Foam Expansion Ratio | 7.0:1 | 9.7:1 | 10.0:1 | 7.5:1 | 7.8:1 | 7.7:1 |
| 25 Percent Solution Drain Time Sec | 377 | 294 | 283 | 330 | 405 | 360 |

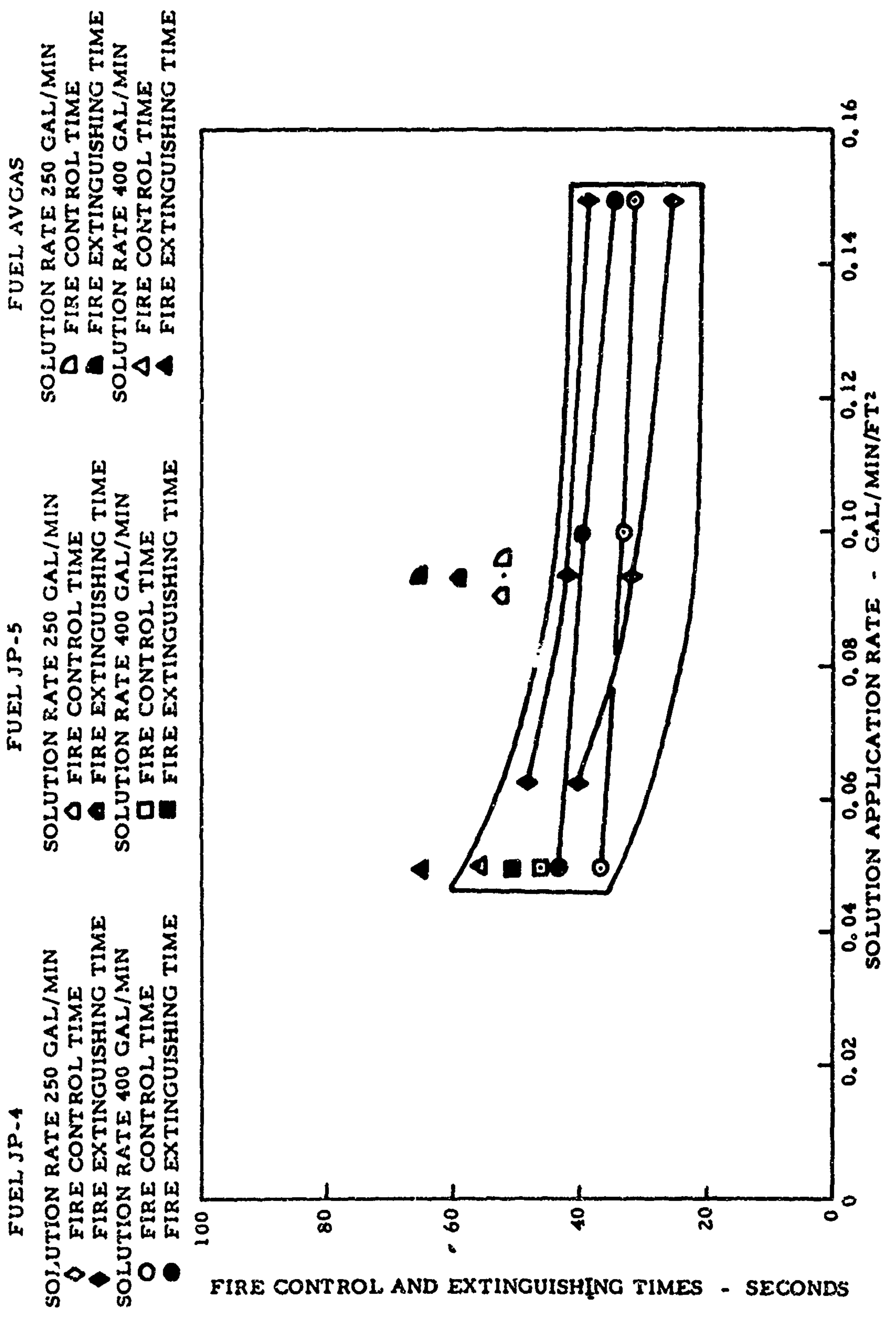


FIGURE 6. FIRE CONTROL AND EXTINGUISHING TIMES AS FUNCTIONS OF THE FOAM SOLUTION APPLICATION RATE USING MANUFACTURER A's AFFF AGENT AT 250 AND 400 GAL/MIN ON JP-4, JP-5, AND AVGAS FIRES

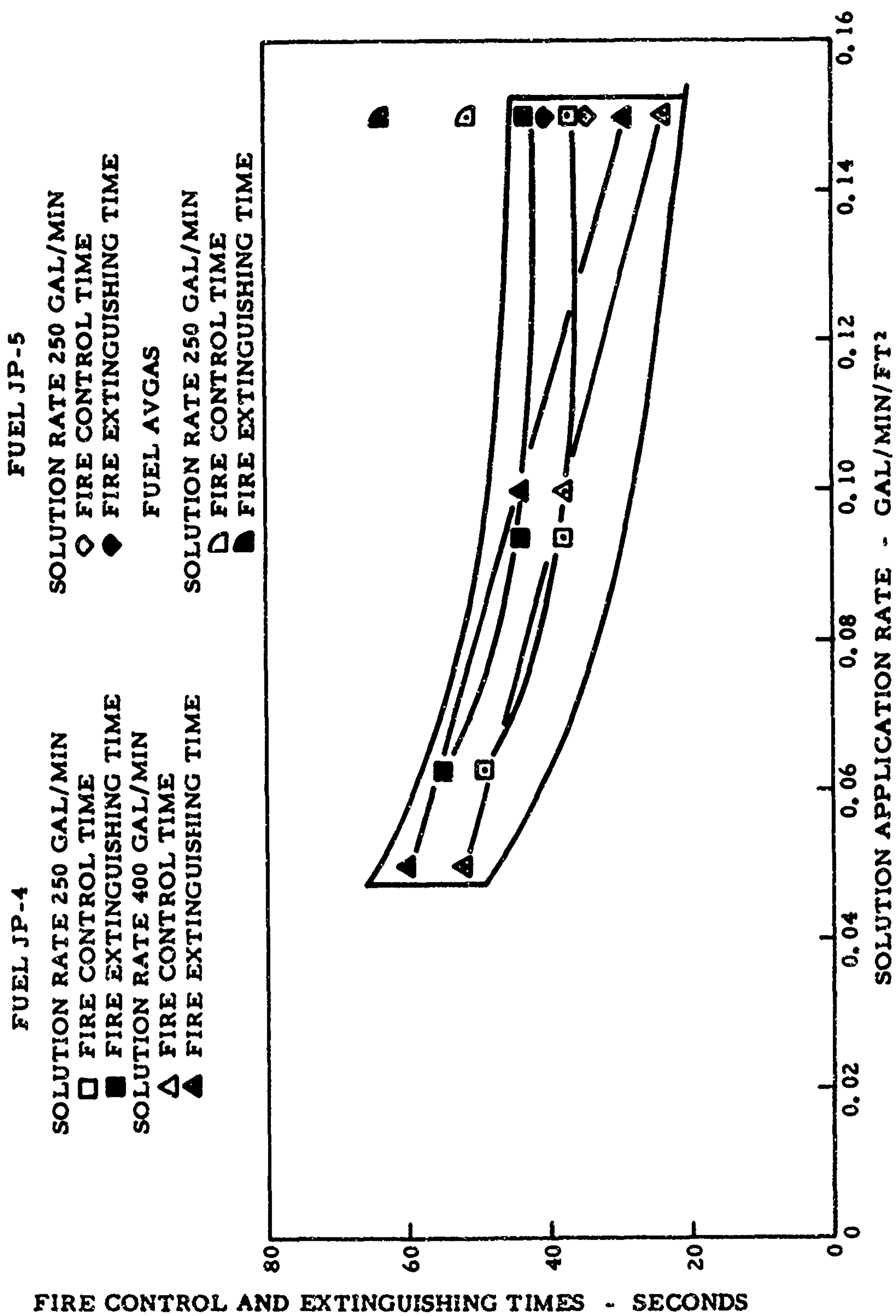


FIGURE 7. FIRE CONTROL AND EXTINGUISHING TIMES AS FUNCTIONS OF THE FOAM SOLUTION APPLICATION RATE USING MANUFACTURER B's AFFF AGENT AT 250 AND 400 GAL/MIN ON JP-4, JP-5 AND AVGAS FIRES

Firefighting Effectiveness of AFFF Agents. Full-scale fire-modeling experiments were conducted to establish the optimum solution application rates of the AFFF agents on traprock base fires using JP-4, JP-5 and avgas fuels. The results of these tests employing Foam Nozzles A and B with solution discharge rates of 250 and 400-gal/min, respectively, are presented in Tables 7 and 8 for Manufacturer A's agent and the data plotted in Figure 6. The fire control and extinguishing time data developed for Manufacturer B's agent using the same foam dispensing equipment are shown in Tables 9 and 10 and the values obtained are indicated by the profiles in Figure 7.

In Figure 6 the fire control and extinguishing times for JP-4 fuel fires are plotted as functions of the foam solution application rates for Foam Nozzles A and B and the AFFF agent supplied by Manufacturer A. The data indicate that at a solution discharge rate of 250-gal/min the fire control times for JP-4 fuel fires of 1,666, 2,666 and 4,000 square feet decreased from 40 to 25 seconds as the foam solution application rate increased from 0.0625 to 0.15 gal/min/sq ft. The time required to extinguish these fires varied from approximately 22 to 56 percent longer than the fire control times.

Two additional experiments were conducted with Manufacturer A's agent to determine its firefighting effectiveness on JP-5 and avgas fires using Foam Nozzle A at an application rate of 0.094 gal/min/sg ft. The results of these experiments are plotted in Figure 6 for comparison with the data obtained using JP-4 fuel. These data show that the time required to control both the JP-5 and avgas fires was 52 seconds and that the extinguishing times varied by only 6 seconds in favor of the JP-5 fuel fires.

Another series of experiments was performed with Manufacturer A's AFFF agent using one 400-gal/min barrel of Foam Nozzle B at solution application rates of 0.05, 0.10 and 0.15-gal/min/sq ft on JP-4 fuel fires. The results of these tests are indicated by the fire control and extinguishing time profiles presented in Figure 6 which show that the fire control times for JP-4 fuel fires of 2,666, 4,000 and 8,000 sq ft decreased from 37 to 31 seconds as the solution application rate increased from 0.05 to 0.15 gal/min/sq ft. The times required to extinguish these fires varied from approximately 16 to 10 percent longer than the fire control times.

Two additional experiments were also performed at solution application rates of 0.05-gal/min/sq ft in which JP-5 and avgas were substituted for the JP-4 fuel. The results of these experiments are presented in Table 8 and the data plotted in Figure 6.

These data show that at a foam solution application rate of 0.05-gal/min/sq ft the fire control and extinguishing times were longest for avgas fires and shortest for JP-4 fuel fires while the values obtained for JP-5 lay between these extremes. This relationship is in general accord with that obtained with Manufacturer A's agent using the 250-gal/min foam nozzle at a solution application rate of 0.094-gal/min/sq ft in that the fire control time obtained for JP-4 fuel fires was less than for either JP-5 or avgas fires.

TABLE 7. FULL-SCALE FIRE-MODELING EXPERIMENTS USING MANUFACTURER A's AFFF AGENT AT 250 GAL/MIN

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 250 | 1666 | 1666 | 0.15 | 500 | - | - | - | 163 | 25 | 39 | 10 |
| 2 | 250 | 2666 | 2666 | 0.094 | 800 | - | - | - | 175 | 32 | 42 | 33 |
| 3 | 250 | 4000 | 4000 | 0.0625 | 1200 | - | - | - | 204 | 40 | 49 | 28 |
| 4 | 250 | 2666 | 2666 | 0.094 | - | - | 800 | - | 271 | 52 | 65 | 51 |
| 5 | 250 | 2666 | 2666 | 0.094 | - | 800 | - | - | 246 | 52 | 59 | 73 |

TABLE 8. FULL-SCALE FIRE-MODELING EXPERIMENTS USING FOAM NOZZLE B AND MANUFACTURER A's AFFF AGENT AT 400 GAL/MIN

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 400 | 2666 | 2666 | 0.15 | 800 | - | - | - | 227 | 31 | 34 | 321 |
| 12 | 400 | 4000 | 4000 | 0.10 | 1200 | - | - | - | 267 | 33 | 40 | 320 |
| 13 | 400 | 8000 | 8000 | 0.05 | 2400 | - | - | - | 287 | 37 | 43 | 333 |
| 14 | 400 | 8000 | 8000 | 0.05 | - | - | 2400 | - | 433 | 56 | 65 | 127 |
| 15 | 400 | 8000 | 8000 | 0.05 | - | 2400 | - | - | 340 | 46 | 51 | - |

TABLE 9. FULL-SCALE FIRE-MODELING EXPERIMENTS USING FOAM NOZZLE BAND MANUFACTURER A's AFFF AGENT AT 400 GAL/MIN

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 250 | 1666 | 1666 | 0.15 | 500 | - | - | 179 | - | 38 | 43 | 191 |
| 7 | 250 | 2666 | 2666 | 0.094 | 800 | - | - | 183 | - | 39 | 44 | 55 |
| 8 | 250 | 4000 | 4000 | 0.0625 | 1200 | - | - | 229 | - | 49 | 55 | 50 |
| 9 | 250 | 1666 | 1666 | 0.15 | - | - | 500 | 263 | - | 51 | 63 | 86 |
| 10 | 250 | 1666 | 1666 | 0.15 | - | 500 | - | 171 | - | 35 | 41 | 81 |

The results of fire control and extinguishing experiments using Manufacturer B's AFFF agent at solution discharge rates of 250 and 400 gal/min are presented in Tables 9 and 10, respectively, and the same data are plotted in Figure 7.

One pair of profiles in Figure 7 show the fire control and extinguishing times for Manufacturer B's agent on JP-4 fuel fires using Foam Nozzle A as functions of the solution application rates. These data indicate that the fire control times for JP-4 fires of 1,666, 2,666 and 4,000 sq ft using a discharge rate of 250-gal/min decreased from 49 to 38 seconds as the foam solution application rate increased from 0.0625 to 0.15-gal/min/sq ft. The time to extinguish these fires varied from approximately 12.5 to 13.0 percent longer that the fire control times.

A second series of experiments was conducted with Manufacturer B's agent on JP-5 and avgas fires using the 250-gal/min foam nozzle at an application rate of 0.15-gal/min/sq ft. The results of these experiments are included in Figure 7 for comparison with the results obtained using JP-4 fuel. These data show that the JP-5 fuel fire was brought under control and extinguished more rapidly using Manufacturer B's AFFF than either the JP-4 or avgas fires. Of the three fuels employed in these experiments, avgas was more difficult to control and extinguish than either JP-4 or JP-5 fires. No experiments were conducted on JP-5 or avgas fuel fires using Foam Nozzle B with Manufacturer B's AFFF agent.

It is noteworthy that the fire control and extinguishing times for avgas fires using either AFFF agent did not vary significantly with changes in the solution application rate which suggests that the high-evaporation rate (low average molecular weight) of the avgas is a controlling factor in the fire control and extinguishing process. The phenomenon is not a unique property limited to avgas compositions since other hydrocarbons and hydrocarbon mixtures have shown anamalous performances which were unpredictable from a consideration of the hydrocarbons as a class of agents. Fuel evaporation rate studies reported by the Naval Research Laboratory (NRL) in Reference 1 showed that the evaporation rate of the narrow-range boiling-point compound N-heptane was not lowered appreciably through the use of AFFF foam. Therefore, it is not improbably that other compounds or combinations of compounds of the homologous series, of which N-heptane is a member, could produce variations in the vapor-securing effectiveness of the aqueous fluorocarbon film. As a consequence of these data, it is apparent that foam solution application rates should be established experimentally for each fuel or hazardous liquid to be protected.

The effect of fuel type on fire control time shows that avgas was more difficult to control and extinguish than either JP-4 or JP-5 fuels which in general confirms the results reported in Reference 9. The time to control JP-5 fuel fires using Manufacturer A's agent at solution application rates of 0.094-gal/min/sq ft with Nozzle A and at 0.15-gal/min/sq ft using Nozzle B was longer for JP-5 than for JP-4 fuel fires. These results did not confirm the results of tests reported by the NRL Reference 9, where experiments using one AFFF agent with JP-5 fuel showed the fire control

TABLE 10. FULL-SCALE FIRE MODELING EXPERIMENTS USING FOAM NOZZLE B AND MANUFACTURER B's AFFF AGENT AT 400 GAL/MIN

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 400 | 2666 | 2666 | 0.15 | 800 | - | - | 260 | - | 23 | 39 | 333 |
| 17 | 430 | 4000 | 4000 | 0.10 | 1200 | - | - | 287 | - | 37 | 43 | 62 |
| 18 | 400 | 8000 | 8000 | 0.05 | 2400 | - | - | 293 | - | 52 | 60 | 110 |

time to be less than that required for JP-4 fires. However, the results are consistent with the data presented in Table 4 of this report which shows that Manufacturer A's, B's, and C's AFFF agents were all less stable on JP-5 fuel than either JP-4 or avgas. At a solution application rate of 0.15-gal/min/sq ft using Nozzle A and Manufacturer B's agent, the fire control time for JP-5 fuel fires was 35 seconds and for JP-4 fires it was 38 seconds which tends to indicate that the apparent foam destructiveness of JP-5 fuel can be compensated for by increasing the foam solution application rate.

A direct comparison of the fire control and extinguishing times using Manufacturer A's and B's agent at solution application rates between 0.05 and 0.15 gal/min/sq ft on JP-4 fuel fires can be estimated from the superimposed envelopes presented in Figure 8. These envelopes contain the same information as those presented in Figures 6 and 7 for each AFFF agent and show the area of overlap which indicates equivalent fire control and extinguishing performance.

The stability or burnback resistance of an AFFF blanket after the Class B fire has been extinguished, except for small Class A, D, or three-dimensional fires, is an important physical property of the foam under full-scale firefighting conditions. Attempts to quantitatively measure the burnback times of each foam, by the method outlined in a previous section of this report, were limited to an estimation of the relative stability of each AFFF foam blanket under equivalent fire conditions. The difficulty in obtaining reproducible results under all test conditions was caused by variable outdoor environmental conditions and the requirement to control and extinguish the fires in the shortest possible times, which precluded the possibility of building up a foam blanket of uniform depth over the entire fire area. Therefore, the burnback times presented in the tables for each experiment were influenced by variations in the depth and uniformity of the foam blanket and the various environmental differences associated with outdoor testing procedures. Accordingly, the values shown for the burnback times are those associated with the test conditions which were maintained during each experiment and are not subject to direct quantitative comparison with one another.

The burnback times were also influenced in part by the degree of "secondary-foam" development associated with each AFFF agent. As a result of the unique property of AFFF to produce an aqueous film on the surface of hydrocarbon liquids, as noted in References 1 and 10, a phenomenon known as secondary-foam development may occur with certain of the more volatile hydrocarbon fuels. The secondary foam is composed of a multitude of fuel-vapor-filled bubbles caused by the normal vaporization of the fuel. When ignited the fuel in the vapor-filled cells burns and leaves a depression or trail in the foam blanket. This phenomenon is sometimes referred to as "flame-wicking." The extent of flame-wicking is considered an important physical property of the AFFF agents when they are employed to control and extinguish the more volatile aircraft fuels. The effects of flame-wicking were photographed extensively

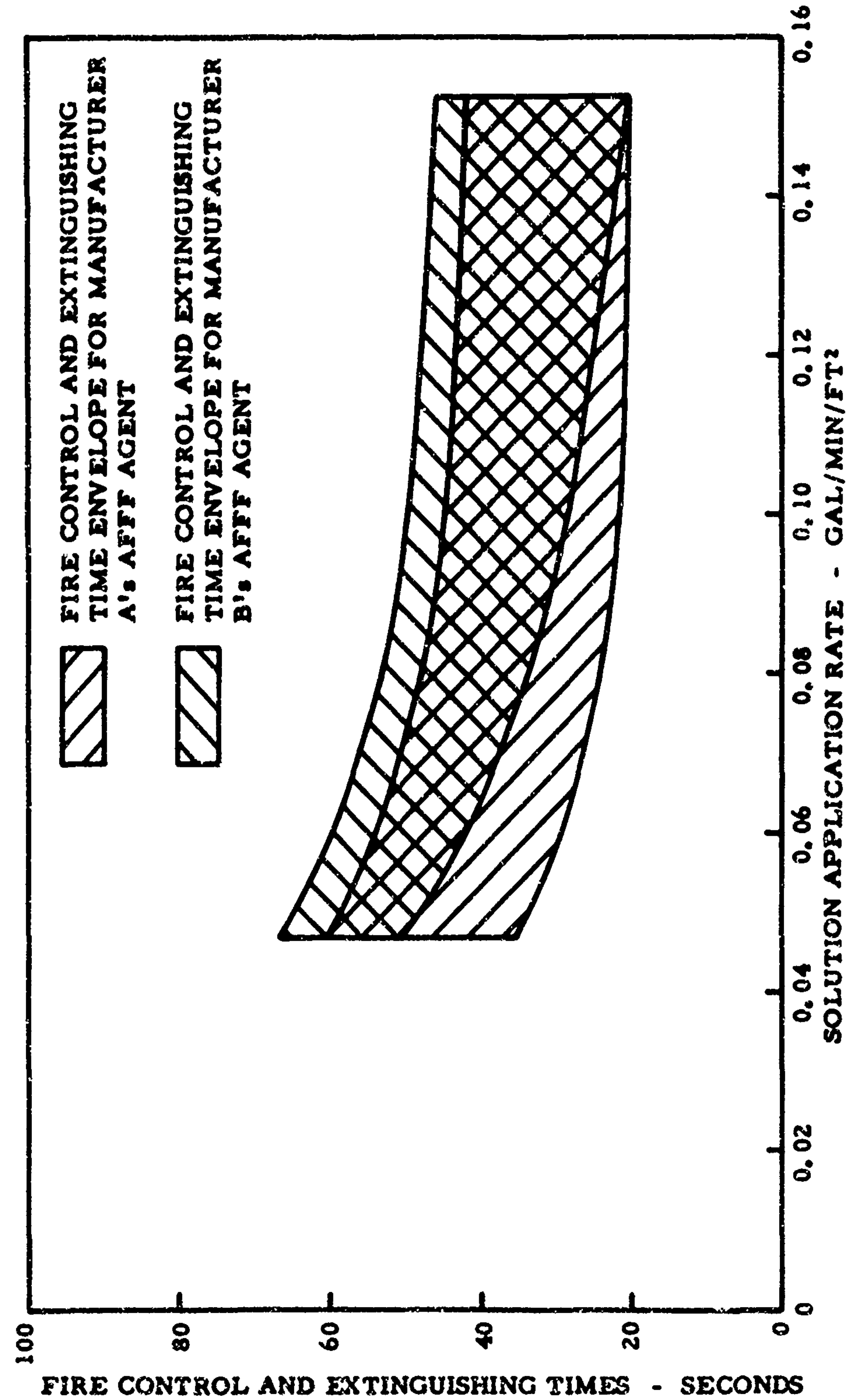


FIGURE 8. COMPARISON OF THE FIRE CONTROL AND EXTINGUISHING TIMES FOR MANUFACTURER A's AND B's AFFF AGENTS AT 250 AND 400 GAL/MIN ON JP-4 FUEL FIRES

during the full-scale fire modeling experiments, and as a result of photographic analysis, it was evident that Manufacturer B's AFFF agent demonstrated a somewhat lesser tendency to produce flame-wicking than Manufacturer A's agent under the same test conditions.

Typical "trails" left by the burned secondary fuel-vapor filled foam bubbles produced by the AFFF agents are shown in Figure 9.

<u>Firefighting Effectiveness of Sprayed Solutions of AFFF</u>. A series of experiments was performed to evaluate the firefighting effectiveness of Manufacturer A's and Manufacturer B's AFFF agents at solution rates of 250, 400, and 800 gal/min through water-spray nozzles. The equipment used in these tests were a 250-gal/min water unit and the 400/800-gal/min water barrels of Nozzle B. Both nozzles were equipped with adjustable stream dispersers which permitted the use of either a straight stream or dispersed pattern. The 250-gal/min nozzle is shown in Figure 10 and the water barrels of Nozzle B are indicated in Figure 4. The firefighting procedures and test bed configuration used in these solution spray experiments were similar to those employed for the foam tests.

The intent of these experiments was to determine if a sprayed solution of AFFF was capable of extinguishing an 8,000-sq ft JP-4 fuel fire at solution application rates of 0.03, 0.05 and 0.10 gal/min/sq ft. It was anticipated that because of the low surface tension of the AFFF solution and the high-shearing action caused by its passage through the air that an effective fire extinguishing foam would be produced.

The results of these experiments are given in Table 11 and the data plotted in Figures 11 and 12. The profiles in Figure 11 show the fire control and extinguishing times for Manufacturer A's agent and in Figure 12 those for Manufacturer B's agent.

The results of these experiments indicate that aqueous solutions of the AFFF agents were capable of obtaining control and final extinguishment of JP-4 fuel fires at moderate to low (0.10 to 0.035-gal/min/sq ft) solution application rates with the single exception of Manufacturer B's agent at 0.035 gal/min/sq ft which did not extinguish the fire. This performance is significant in that it was estimated that the foam expansion ratio was less than 2:1 for both agents and the solution drainage time too rapid to be determined by the method presented in Reference 8 for AFFF foams.

A comparison of the fire control time profiles presented in Figures 8 and 11 shows that control was obtained by foam in 34 seconds using Manufacturer A's agent at a solution application rate of 0.10 gal/min/sq ft on a 4,000-sq ft JP-4 fuel fire. When a 6-percent water solution of the same agent was dispensed at the same rate on an 8,000-sq ft fire, the control time was 35 seconds. As the solution application rate was reduced to 0.05 gal/min/sq ft for foam, the fire control time increased to 38 seconds and for the water solution it was 51 seconds.

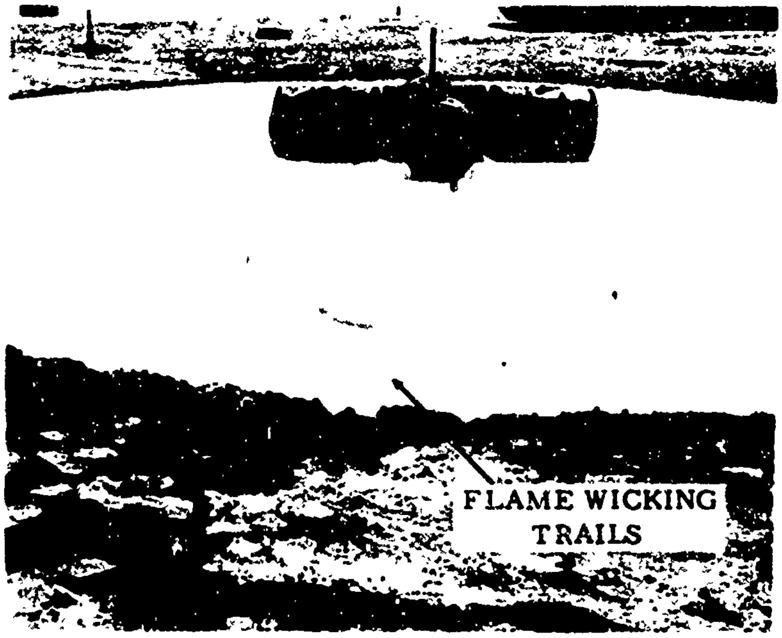


FIGURE 9-1. TRAILS LEFT BY MANUFACTURER A's AFFF AGENT


FIGURE 9-2. TRAILS LEFT BY MANUFACTURER B's AFFF AGENT

FIGURE 9. "TRAILS" LEFT BY THE BURNED SECONDARY FUEL-VAPOR-FILLED FOAM PRODUCED BY MANUFACTURER A's AND MANUFACTURER B's AFFF AGENTS

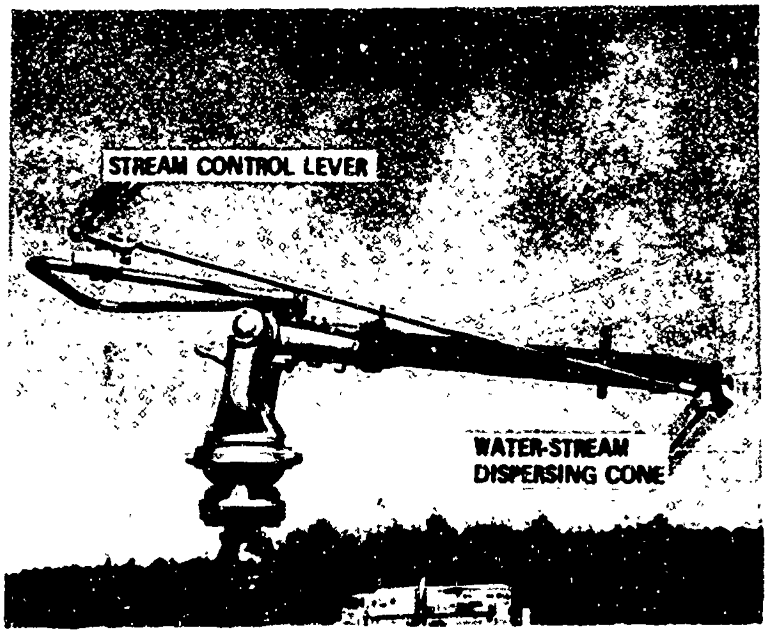


FIGURE 10-1. PROFILE VIEW

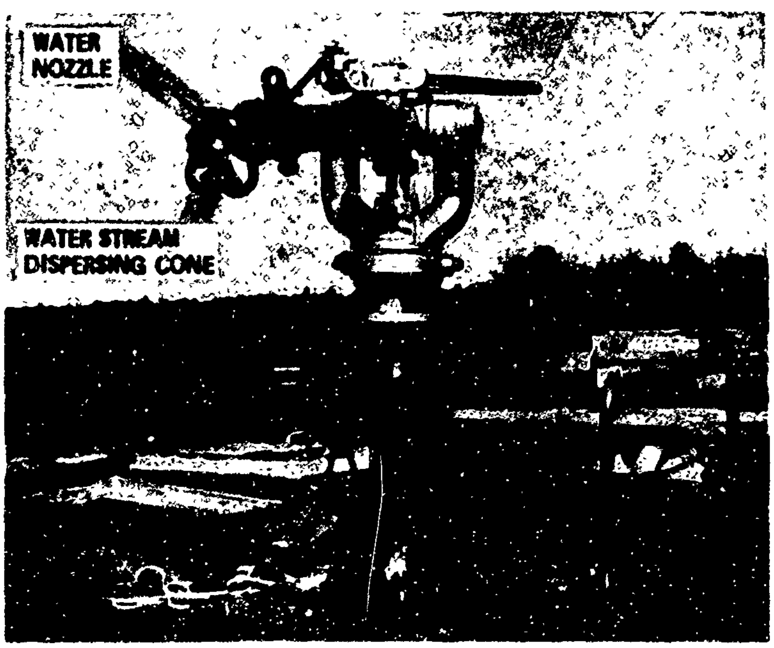


FIGURE 10-2. FRONT VIEW

FIGURE 10. GENERAL CONFIGURATION OF THE 250-GAL/MIN WATER-SPRAY NOZZLE

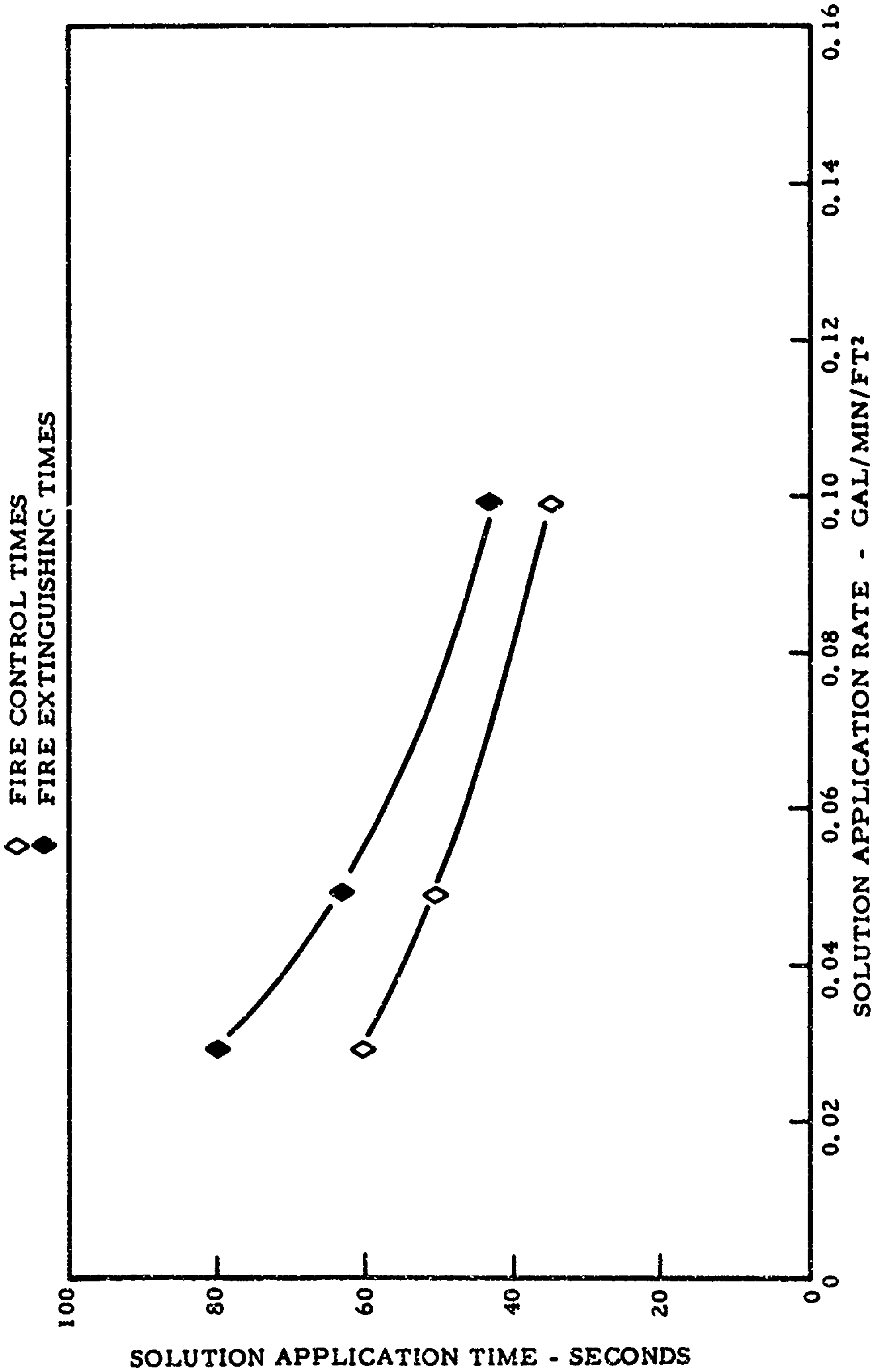


FIGURE 11. FIRE CONTROL AND EXTINGUISHING TIMES AS FUNCTIONS OF THE SOLUTION APPLICATION RATES USING MANUFACTURER A's AGENT AT 250, 400, AND 800 GAL/MIN ON 8000-SQ FT JP-4 FUEL FIRES

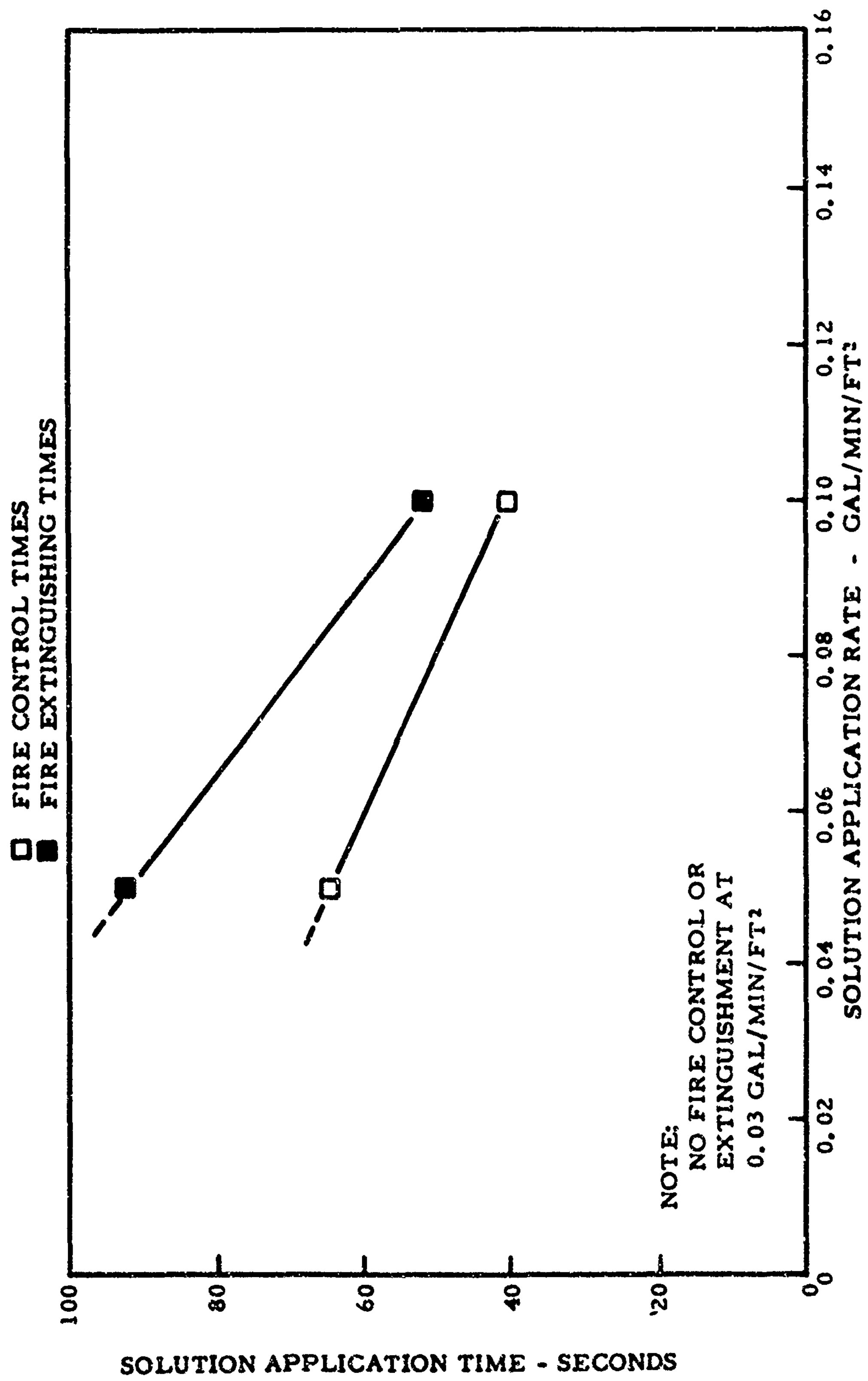


FIGURE 12. FIRE CONTROL AND EXTINGUISHING TIMES AS FUNCTIONS OF THE SOLUTION APPLICATION RATES USING MANUFACTURER B's AGENT AT 250, 400 AND 800 GAL/MIN ON 8000-SQ FT JP-4 FUEL FIRES

TABLE 11. FULL-SCALE FIRE-MODELING EXPERIMENTS USING WATER-SPRAY DISCHARGE OF SOLUTIONS OF THE AFFF AGENTS AT 250, 400, AND 800 GAL/MIN

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | JP-5 (gal) | Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 250 | 8000 | 8000 | 0.03 | 2400 | - | - | - | - | None | None | - |
| 20 | 400 | 8000 | 8000 | 0.05 | 2400 | - | - | 613 | - | 65 | 92 | 26 |
| 21 | 800 | 8000 | 8000 | 0.10 | 2400 | - | - | 693 | - | 41 | 52 | 172 |
| 22 | 250 | 8000 | 8000 | 0.03 | 2400 | - | - | - | 312 | 61 | 81 | 103 |
| 23 | 400 | 8000 | 8000 | 0.05 | 2400 | - | - | - | 420 | 51 | 63 | - |
| 24 | 800 | 8000 | 8000 | 0.10 | 2400 | - | - | - | 573 | 35 | 43 | - |

A similar comparison between foam and sprayed solutions of Manufacturer B's agent (Figures 8 and 12) shows that at a solution application rate of 0.10 gal/min/sq ft the fire control time with foam was 37 seconds which was increased to 41 seconds for the water solution discharge. When the solution application rate was decreased to 0.05 gal/min/sq ft, the fire control time for foam was 52 seconds and for the water solution it was 65 seconds. As the water solution application rate was further reduced to 0.03 gal/min/sq ft, neither fire control nor extinguishment was obtained.

From the fire test sequence presented pictorially in Figure 13, it is evident that some scattered light-patchy foam remained on the fuel surface after fire extinguishment. However, during the initial phase of foam application, the flame knockdown was visually more rapid than would have been anticipated on the basis of foam quality alone. Therefore, it was speculated that the AFFF solution was successful, in part, because the water solution was very finely dispersed as a result of its low-surface tension and passage through the air; and that some of the fluorocarbon surfactants were pyrolyzed and liberated a sufficient quantity of free radical moieties to effectively inhibit flame propagation. This mechanism of flame inhibition is suggested as one factor which may contribute to the overall firefighting effectiveness of sprayed solutions of the AFFF agents. To obtain additional background information and as a control, one experiment was conducted using water spray alone on a 4,000-sq ft JP-4 fuel fire at a rate of 0.065 gal/min/sq ft. The result of this experiment showed that water spray alone was unable to make any significant progress toward controlling and extinguishing the fire.

<u>A Determination of the Fire Control and Extinguishing Times of Different Size Segments of Large JP-4 Fuel Fires Using AFFF</u>. A series of 10 experiments was performed with Manufacturer A's and Manufacturer B's AFFF agents to evaluate the relative fuel-vapor-securing properties and burnback time of these foams when exposed to high-heat flux during application on partially controlled JP-4, JP-5, and avgas fuel fires. In these experiments the requirement was to apply AFFF foam on 4,000 and 5,000 sq ft of fire when the total area was 6,000 sq ft and on 2,500 sq ft of fire when the total area was 4,000 sq ft. Solution application rates of 0.05 and 0.10 gal/min/sq ft were obtained using Foam Nozzle A (250 gal/min) and one barrel of Foam Nozzle B (400 gal/min) on test beds of different sizes and configurations. A list of the experiments performed is presented in Table 12 and a plan view of the fire test bed is shown in Figure 14. The fire pit was divided visually into two areas by seven 3-foot-high steel pipes placed across the pit parallel with the wind direction to enable the nozzle operator to make a more precise application of foam on the area to be covered. A cruciform configuration of 55-gal steel drums and the three-dimensional fire were located in the center of the fire area to be covered by foam in each test.

The objective of these experiments was to extinguish a particular fire area as rapidly as possible starting with the fully dispersed foam pattern and adjusting the stream as required to achieve the necessary range.

FIGURE 13-1. INITIAL SOLUTION ATTACK WITH FULLY DISPERSED STREAM

FIGURE 13-2. FULLY DISPERSED SOLUTION STREAM BEING CHANGED TO SOLID STREAM FOR GREATER RANGE

FIGURE 13-3. SOLID STREAM SOLUTION PATTERN BEING USED FOR MAXIMUM RANGE

FIGURE 13-4. FIRE EXTINGUISHED

FIGURE 13. FOUR CRITICAL PHASES DURING THE FIRE CONTROL AND EXTINGUISHING OF AN 8000-SQ FT JP-4 FUEL FIRE USING MANUFACTURER A's AGENT AT A SOLUTION DISCHARGE RATE OF 800 GAL/MIN

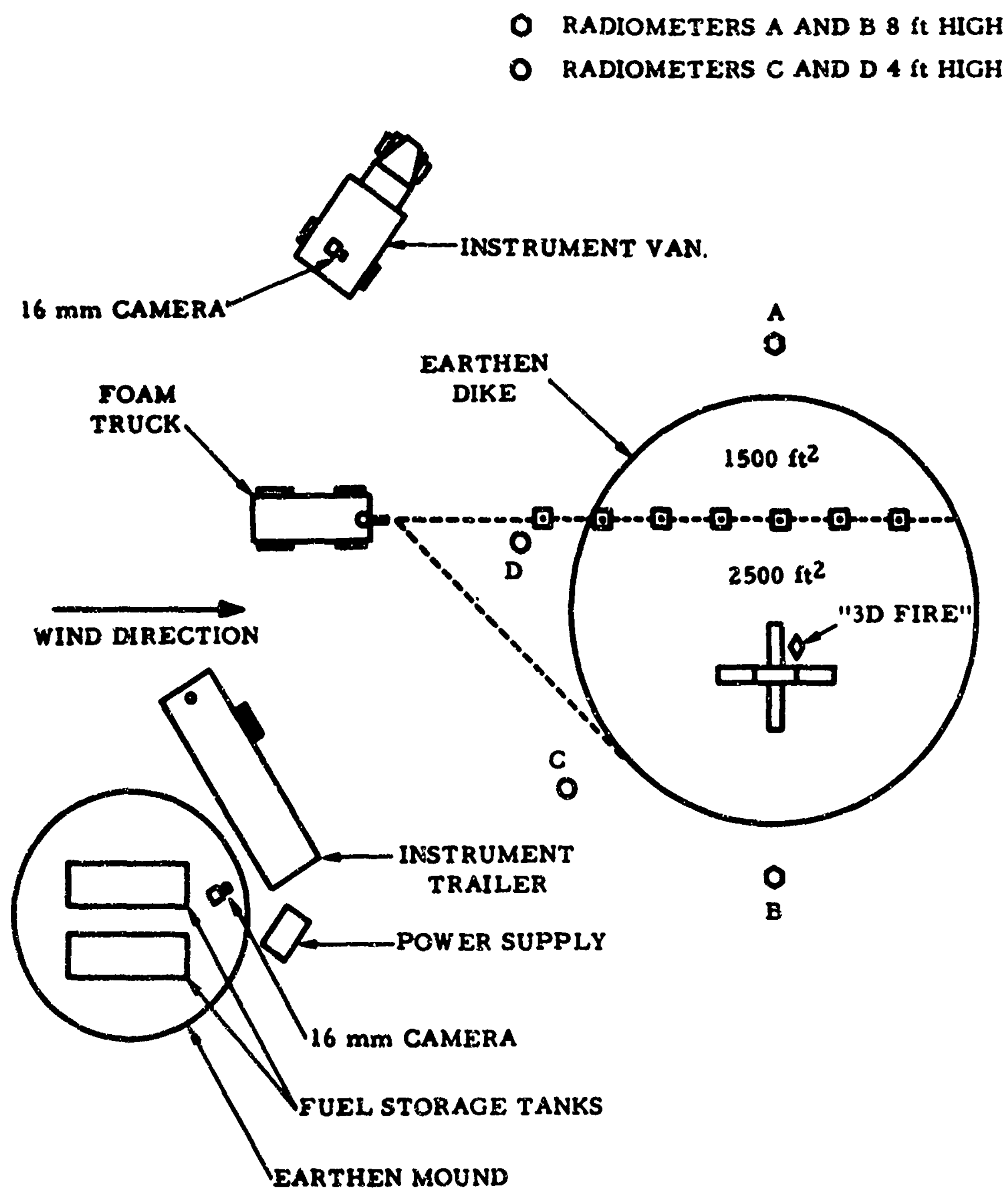


FIGURE 14. PLAN VIEW OF THE FIRE TEST BED SHOWING THE RADIOMETER AND CAMERA LOCATIONS AND THE ROW OF STEEL PIPES

TABLE 12. FUEL-VAPOR-SECURING EFFECTIVENESS OF AFFF BLANKETS ON PARTIALLY CONTROLLED AIRCRAFT FUEL FIRES

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 250 | 4000 | 2500 | 0.10 | 1200 | - | - | - | 271 | 21.5 | 65 | 110 |
| 26 | 250 | 8000 | 5000 | 0.05 | 2400 | - | - | - | * | 59 | - | - |
| 27 | 250 | 4000 | 2500 | 0.10 | 1200 | - | - | 146 | - | 25 | 35 | 115 |
| 28 | 250 | 8000 | 5000 | 0.05 | 2400 | - | - | * | - | None | None | - |
| 29 | 250 | 4000 | 2500 | 0.10 | - | - | 1200 | 395 | - | 69 | 95 | 360 |
| 30 | 250 | 8000 | 5000 | 0.05 | - | - | 2400 | - | * | 62 | - | - |
| 31 | 250 | 4000 | 2500 | 0.10 | - | 1200 | - | 217 | - | 37 | 52 | - |
| 32 | 250 | 8000 | 5000 | 0.05 | - | 2400 | - | - | * | 69 | - | - |
| 33 | 400 | 8000 | 4000 | 0.10 | 2400 | - | - | - | 247 | 21 | 37 | 110 |
| 34 | 400 | 8000 | 4000 | 0.10 | 2400 | - | - | 233 | - | 26 | 35 | 166 |

*Total solution applied during test.

A typical fire test sequence is shown in Figure 15. Figure 15-1 shows the fire test bed with the pipe-sighting markers in place and two radiometers on the upwind side of the fire pit. Figure 15-2 shows the start of AFFF application with foam being applied to the upwind edge of the pool perimeter. Figure 15-3 shows the stream laying a curtain of foam along the sighting pipes in the final extinguishing phase, and Figure 15-4 shows the right side of the pit after the fire was brought under control and extinguished.

The results of the 10 experiments are presented in Table 12 which shows the fire control and extinguishing times obtained with the two AFFF agents at solution discharge rates of 250 and 400-gal/min on three different fire segments (2,500, 4,000 and 5,000 sq ft) in two different fire sizes (4,000 and 8,000 sq ft). These data show that Manufacturer A's agent applied at a solution rate of 0.10 gal/min/sq ft controlled a 2,500-sq-ft segment of a 4,000-sq-ft circular JP-4 fuel fire in 21.5 seconds and extinguished it in 65 seconds while Manufacturer B's agent required 28 seconds for control and 39 seconds to extinguish a fire of equivalent size. These results do not indicate any significant difference in the overall firefighting effectiveness between the two agents at a solution application rate of 0.10 gal/min/sq ft.

Similar experiments using the same foam-dispensing equipment employed in the previous tests but using a larger area of foam application (5,000 sq ft) on an 8,000-sq ft JP-4 fuel fire, which reduced the foam solution application rate from 0.10 to 0.05 gal/min/sq ft, indicated that Manufacturer A's AFFF yielded borderline performance in that it controlled but did not extinguish the area of foam application and that a solution application rate of 0.05 gal/min/sq ft for Manufacturer B's agent was below the critical value required to obtain fire control and extinguishment. The critical foam solution application rate is defined in this report as the lowest rate at which a Class B (Reference 11) fire can be progressively brought under control and extinguished by the continuous uniform application of foam.

These experimental results tend to show that a large flame front adjacent to an AFFF foam blanket in the process of being established may be subject to some decomposition caused by the intense thermal radiation from the fire plume. Therefore, under actual crash fire conditions where an aircraft occupant escape route is in the process of being established, an effort should be made to apply the AFFF at rates commensurate with the thermal requirements of the environment.

The effect of fuel type on the fire control and extinguishing times using Manufacturer B's AFFF agent at a solution rate of 0.10 gal/min/sq ft using Foam Nozzle A, indicated that the shortest fire control and extinguishing times were obtained with JP-4 fuel while avgas required the longest times. The fire control and extinguishing times for JP-5 fuel fires were found to lie between the values obtained for JP-4 and avgas fires.

FIGURE 15-1. FIRE TEST BED

FIGURE 15-2. INITIAL FOAM APPLICATION

FIGURE 15-3. FIRE APPROACHING CONTROL

FIGURE 15-4. TEST BED AFTER FOAM APPLICATION

FIGURE 15. FIRE TEST SEQUENCE SHOWING THE METHOD OF APPLYING AFFF FOAM TO A SPECIFIC SEGMENT OF THE TOTAL FIRE AREA

Manufacturer A's AFFF agent applied at a solution application rate of 0.05 gal/min/sq ft by Foam Nozzle A on JP-4, JP-5, and avgas fuel fires indicated that the solution rate was adequate to bring the fires under control in from 59 to 69 seconds but was below the critical application rate required for extinguishment.

The effect of foam solution discharge rate on the fire control and extinguishing times of JP-4 fuel fires was conducted by performing two experiments using one 400-gal/min barrel of Foam Nozzle B with each of the two AFFF agents. The results of these experiments show that Manufacturer A's agent achieved control in 21 seconds and extinguishment in 37 seconds and that Manufacturer B's agent obtained control in 26 seconds and extinguishment in 35 seconds at a solution application rate of 0.10 gal/min/sq ft.

A comparison of these data with those obtained with the 250 gal/min foam nozzle at an equal solution application rate (0.10 gal/min/sq ft) indicates that the fire control and extinguishing times for Manufacturer B's agent at both discharge rates was of the same order of magnitude. Manufacturer A's agent demonstrated an advantage of approximately 43 percent in the fire extinguishing time when it was discharged at 400 gal/min over that obtained at 250 gal/min but this apparently anomalous performance is not considered a significant factor in its overall firefighting performance.

Effect of Single vs Multiple Points of Foam Discharge on Fire Control and Extinguishing Times. The firefighting effectiveness of single versus multiple points of foam discharge on large fuel-spill fires is of significance because of the usual presence of more than one foam-dispensing vehicle at the site of accidents involving large aircraft. The deployment of major foam-dispensing vehicles was evaluated in Reference 10 where each vehicle was assigned a particular fire area to be brought under control as part of an overall firefighting objective involving a B-47 aircraft. However, no full-scale fire-modeling experiments were performed in which a direct comparison between single and multiple discharge points were evaluated at the same solution application rate.

Therefore, four experiments were performed using Manufacturer A's and Manufacturer B's AFFF to determine the difference in firefighting effectiveness between single and double points of foam discharge on 8,000-sq-ft traprock base JP-4 fuel fires. The fire control and extinguishing times from a single point of discharge were determined by employing both barrels of Foam Nozzle B with a solution discharge rate of 800 gal/min which provided a foam application rate of 0.10 gal/min/sq ft. Two points of discharge were obtained by discharging one 400-gal/min barrel from each of two trucks positioned 30 feet apart on the upwind side of the fire pit.

The fire test bed and monitoring system was the same as that shown in Figure 2. The results of the experiments are presented in Table 13. These data show that for two points of foam discharge using Manufacturer A's

TABLE 13. EFFECT OF SINGLE- AND MULTIPLE- NOZZLE DISCHARGE ON THE FIRE CONTROL AND EXTINGUISHING TIMES OF JP-4 FUEL FIRES

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Multiple Nozzle Discharge** | | | | | | | | | | | | |
| 35 | 400<br>400 | 8000 | 8000 | 0.10 | 2500 | - | - | - | 640 | 33 | 48 | 210 |
| 36 | 400<br>400 | 8000 | 8000 | 0.10 | 2500 | - | - | 506 | - | 23 | 38 | 190 |
| **Single Nozzle Discharge** | | | | | | | | | | | | |
| 37 | 800 | 8000 | 8000 | 0.10 | 2400 | - | - | 613 | - | 36 | 46 | 373 |
| 38 | 800 | 8000 | 8000 | 0.10 | 2400 | - | - | - | 600 | 39 | 45 | 224 |
| 39 | 800 | 8000 | 8000 | 0.10 | - | 2400 | - | - | 440 | 28 | 33 | - |
| 40 | 800 | 8000 | 8000 | 0.10 | - | - | 2400 | - | 520 | 32 | 39 | 170 |

AFFF-fire control was obtained in 33 seconds and extinguishment in 48 seconds. For a single point of foam discharge under similar test bed conditions, fire control required 39 seconds and extinguishment 45 seconds.

Similar experiments performed with Manufacturer B's AFFF achieved fire control in 23 seconds and extinguishment in 38 seconds from two points of discharge and fire control in 36 seconds and extinguishment in 46 seconds from a single point of discharge at a solution application rate of 0.10 gal/min/sq ft.

A comparison of the data obtained from these experiments indicates that Manufacturer A's AFFF did not show a significant decrease in the fire control and extinguishing times when foam was dispensed from two separate points over that required for a single point of discharge. However, Manufacturer B's AFFF showed a reduction of approximately 36 percent in the fire control time and approximately 17 percent in the fire extinguishing time when foam was applied from two points of discharge over that required from a single point of discharge.

Two additional experiments were performed in this series to determine the effect of fuel type on the fire control and extinguishing times for Manufacturer A's AFFF at a solution application rate of 0.10 gal/min/sq ft from a single point of discharge. The data obtained from these experiments indicate that JP-4 fuel required the longest time (39 sec) for fire control and JP-5 the shortest (28 sec) while the time for avgas was approximately midway between these two values with a control time of 32 seconds.

Compatibility Between AFFF and Protein Foam. A series of three experiments was performed on 4,000-sq ft JP-4 fuel fires to determine the mutual compatibility between the expanded foams produced by the two AFFF agents and between each AFFF agent and protein foam, and to estimate the degree of secondary foam development associated with each AFFF agent. In these experiments a cruciform configuration of seven 55-gallon steel drums and three-dimensional fire served as an obstacle which provided a means for estimating foam fluidity by requiring it to spread and flow around and behind the drums.

One experiment (Table 14) was performed by discharging each AFFF agent from a 60-gal/min handline in a simultaneous attack on a 4,000-sq ft JP-4 fuel fire. Two additional experiments were conducted, on the same test bed, in which each AFFF agent was discharged individually with protein foam from two 60-gal/min handlines in a combined agent application to extinguish the fires. Each foam agent was applied to one-half of the fire so that the foam blankets overlapped approximately 10 feet down the center of the pit. After the fire had been extinguished, except for the three-dimensional fire in the center of the pit, the overlapping portion of the foams was observed for any unusual breakdown of the blanket and for secondary foam development.

TABLE 14. COMPATIBILITY BETWEEN THE EXPANDED FOAMS PRODUCED BY THE AFFF AGENTS AND BETWEEN AFFF AND PROTEIN FOAM

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Protein (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Handline | | | | | | | | | | | | |
| 41 | 60 | 4000 | 4000 | 0.03 | 1200 | - | - | 75 | - | - | 53 | 75 | 69 |
| | Handline | | | | | | | | | | | | |
| | 60 | | | | | | | | 54 | - | 44 | 54 | 78 |
| | Handline | | | | | | | | | | | | |
| 42 | 60 | 4000 | 4000 | 0.03 | 1200 | - | - | 58 | - | - | 40 | 58 | 13 |
| | Handline | | | | | | | | | | | | |
| | 60 | | | | | | | | | 57 | 44 | 57 | 17 |
| | Handline | | | | | | | | | | | | |
| 43 | 60 | 4000 | 4000 | 0.03 | 1200 | - | - | - | 82 | - | 41 | 82 | 86 |
| | Handline | | | | | | | | | | | | |
| | 60 | | | | | | | | | 105 | 50 | 105 | 60 |

Four critical phases during a test are shown in Figure 16 which were typical of all three experiments.

The results of the three experiments are presented in Table 14. These data indicate that the fire control and extinguishing times for the AFFF agents (Test 41) were of same order of magnitude although Manufacturer B's agent demonstrated an advantage in both the fire control and extinguishing times. In Experiment 42 in which Manufacturer A's AFFF agent was used in a combined application with protein foam, the fire control time was 40 seconds for AFFF and 44 seconds for protein foam with almost identical fire extinguishing times. The results of Experiment 43 employing Manufacturer B's agent and protein foam showed a fire control time of 41 seconds and an extinguishing time of 82 seconds for the AFFF agent while the protein foam required 50 seconds for control and 105 seconds for extinguishment.

In general the fire control times for the two AFFF agents and protein foam were between 40 and 53 seconds and the fire extinguishing times between 54 and 105 seconds. From these data, it is apparent that at a foam solution application density of 0.03 gal/min/sq ft using 60 gal/min handline nozzles any significant differences in foam agent effectiveness were offset by the capability of the nozzle operator to vary the foam distribution pattern and to modify or change the application techniques to achieve the most rapid fire control and extinguishing times.

The flame-wicking of the AFFF foam blankets after the fires were extinguished was determined by probing the edge of the blanket with a lighted torch in an effort to detect any escaping fuel vapors. The extent of wicking was estimated by observing the foam blanket at the end of each test and from an analysis of the documentary camera coverage. In these experiments, flame-wicking was considered minor by comparison with the results observed in larger tests using high-velocity turret nozzles which were presented in a previous section of this report.

At the conclusion of each experiment, the overlapping section of the foam blankets was observed for any evidence of physical or chemical disintegration for as long as practicable. From these observations it was apparent that mixtures of the foams produced by Manufacturer A's and Manufacturer B's AFFF agents were compatible with one another and with protein foam.

The protein foam and AFFF's produced by the 60-gal/min handline nozzles in these experiments were sufficiently fluid to flow around and behind the obstacle in the center of the fire pit and extinguish the fire in that area.

A Method for Estimating the Fire Control and Extinguishing Times of AFFF Agents by Maintaining a Fixed-Fire Size and Varying the Area of Foam Application. A series of experiments was performed to determine the practicability of evaluating the firefighting effectiveness of foam agents at several different solution application rates in full scale fire-modeling

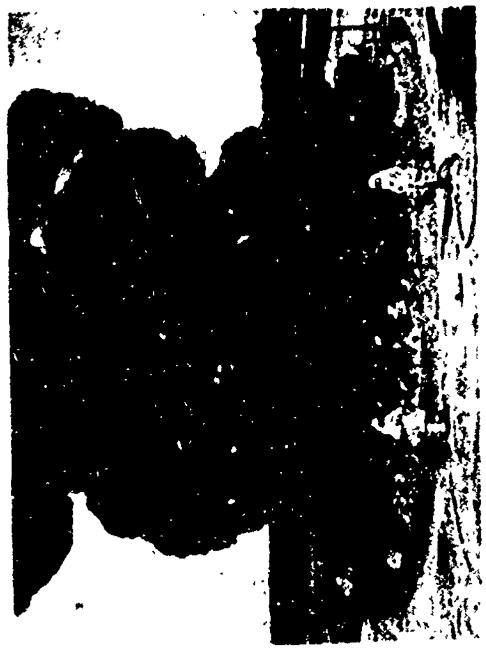

FIGURE 16-1. FIRE PREBURN PERIOD

FIGURE 16-2. INITIAL FOAM ATTACK

FIGURE 16-3. FIRE CONTROL PHASE

FIGURE 16-4. FINAL EXTINGUISHING PHASE

FIGURE 16. FOUR CRITICAL PHASES DURING THE FIRE CONTROL AND EXTINGUISHING OF A JP-4 FUEL FIRE USING TWO 60-GAL/MIN HANDLINE NOZZLES

experiments using a fire area smaller than the foam application area, thereby conserving fuel and reducing atmospheric contamination. The tests were performed by discharging AFFF at solution rates of 400 and 800 gal/min on a test bed comprising a 4,000-sq ft circular traprock base JP-4 fuel fire positioned concentrically in diked areas of 5,333, 8,000, and 16,000 sq ft. A plan view of the fire test bed is presented in Figure 17. The area of foam application is indicated by the large circle and the fire area by the smaller inscribed circle. The obstacle and three-dimensional fire positioned in the center of the fire pit was similar to that shown in Figure 2.

The technique employed to control and extinguish the fire was to apply foam over the total area (5,333, 8,000, or 16,000 sq ft) including the fire pit, starting with the upwind edge of the bunded area and proceeding outward with a uniform side-to-side motion giving particular attention to building up as uniform a foam blanket as possible over the entire area.

The results of the full-scale fire-modeling experiments using both AFFF agents are presented in Table 15.

To verify the adequacy of the foam-dispensing technique in establishing a uniform foam blanket over the entire area of foam application, the fire test bed in Test No. 48 was provided with eight 1-foot-square steel pans distributed as shown in Figure 18 within the fire-free area bounded by the outside rim of the fire and the concentric circular mound defining the maximum limit of foam application. The experiment was conducted by charging each pan and the center pit to a depth of 0.75-inch with JP-4 fuel. All of the satellite pans were ignited prior to torching the center fire pit. At the conclusion of the 15-seconds preburn time, the fires were extinguished by applying Manufacturer A's AFFF at the rate of 0.05 gal/min/sq ft in a uniform pattern over the entire bunded area until all fire areas were extinguished. Under these experimental conditions fire control was obtained in 25 seconds and extinguishment in 35 seconds. After the cessation of foam application, the steel pans were removed and the volume of foam solution in each was measured so that the depth of foam representative of the volume of solution could be calculated. As a result of these calculations, it was determined that the depth of foam over the entire area of application varied between 1.07 and 2.54 inches with an average depth for all pans of 1.78 inches. This residual foam blanket was considered sufficiently uniform and of adequate depth to be representative of the requirements for fire control and extinguishment if the entire bunded area had been covered by fuel, since all fires were extinguished.

The results of six experiments, in which the area of foam application was larger than the fire area, are presented as individual data points in Figure 19 where the foam solution application density is plotted as a function of the foam solution application rate. Two profiles are also included in Figure 19 that show the solution application densities required for fire control of JP-4 fuel fires where the area of foam application was

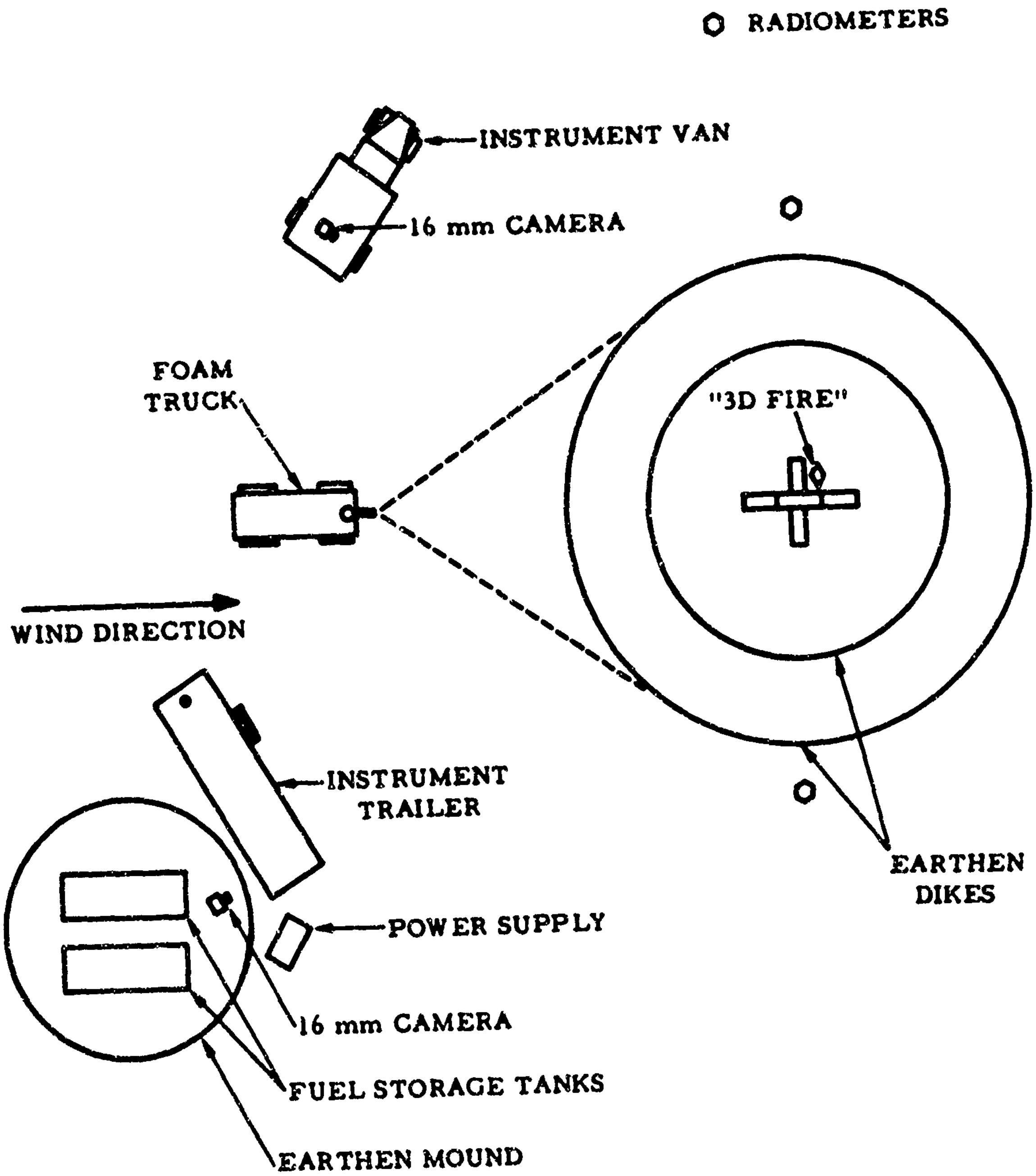


FIGURE 17. PLAN VIEW OF THE FIRE TEST BED SHOWING THE RADIOMETER AND CAMERA LOCATIONS

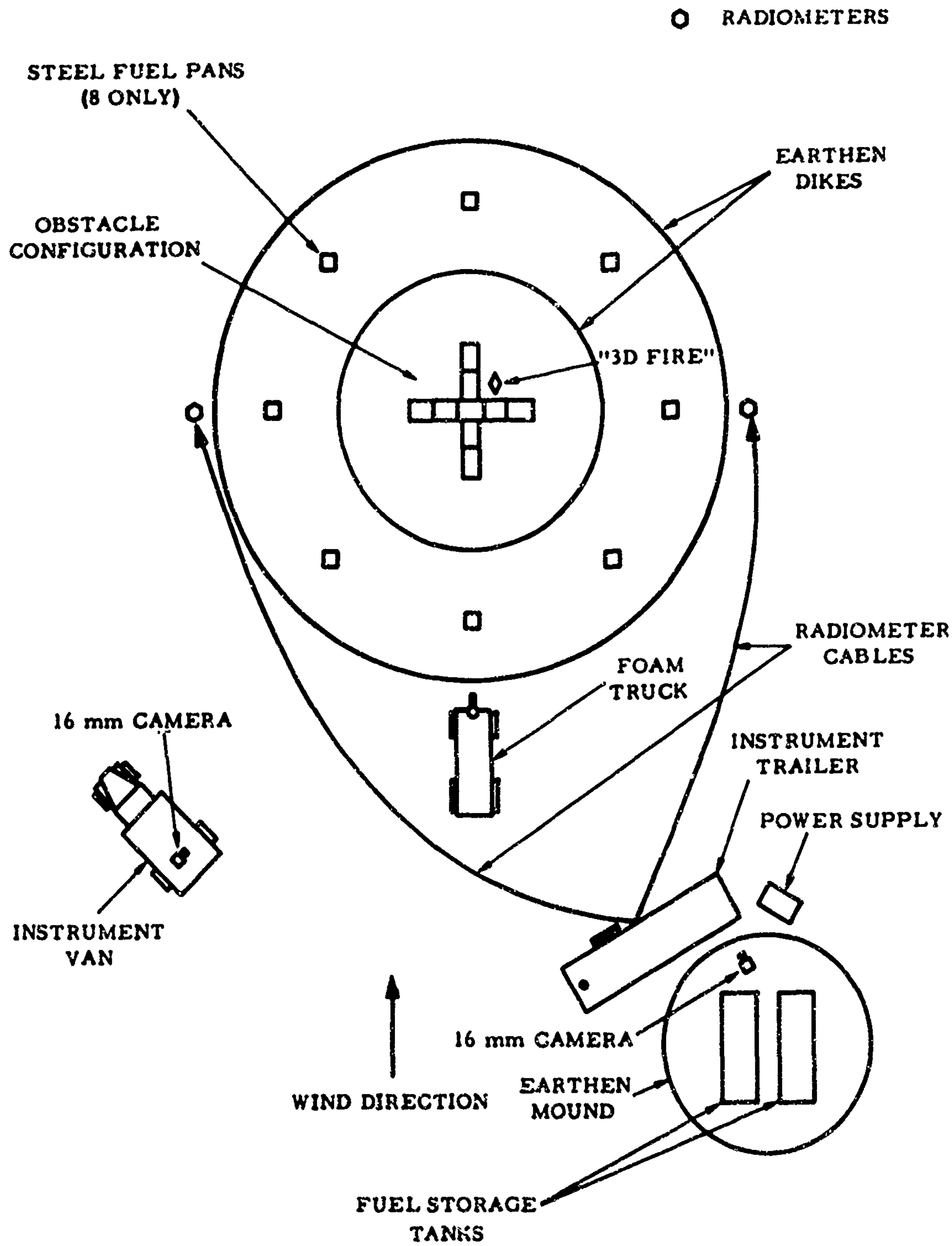


FIGURE 18. PLAN VIEW OF THE FIRE TEST BED SHOWING THE PLACEMENT OF THE FOAM RECEPTACLES FOR MEASURING THE EFFECTIVENESS OF THE FOAM DISTRIBUTION TECHNIQUES

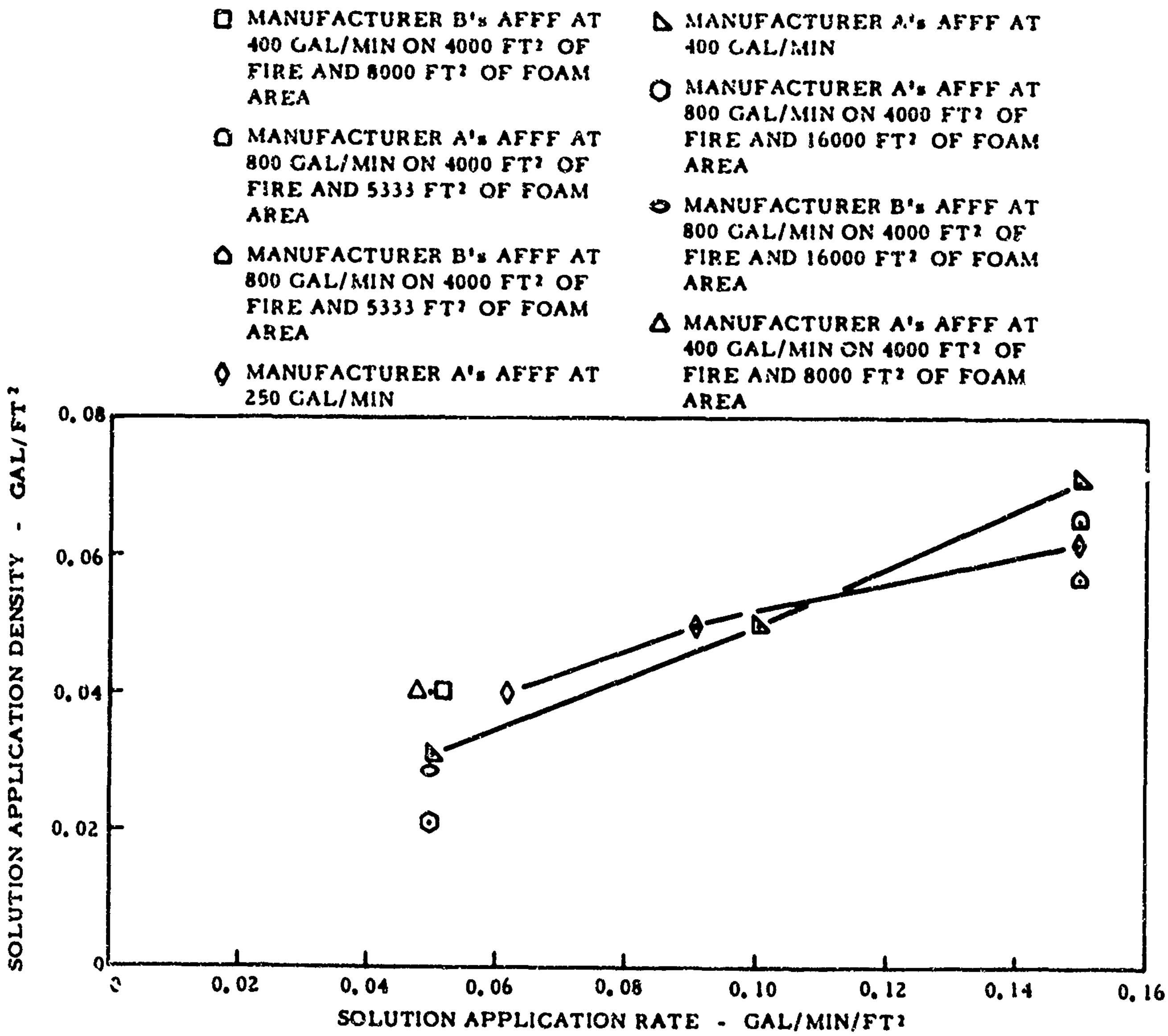


FIGURE 19. FOAM SOLUTION APPLICATION DENSITY AS A FUNCTION OF THE SOLUTION APPLICATION RATE USING MANUFACTURER A's AFFF AGENT ON A FIXED FIRE SIZE AND VARYING THE AREA OF FOAM APPLICATION. PROFILES SHOWING DATA FOR "STANDARD" FIRE TESTS ARE INCLUDED FOR COMPARATIVE PURPOSES

TABLE 15. FIRE CONTROL AND EXTINGUISHING TIMES OF AFFF AGENTS BY MAINTAINING A FIXED FIRE SIZE AND VARYING THE AREA OF FOAM APPLICATION

| Test No. | Solution Discharge Rate (gal/min) | Fire Area (sq ft) | Area of Foam Appl. (sq ft) | Solution Application Rate (gal/min/sq ft) | Fuels JP-4 (gal) | Fuels JP-5 (gal) | Fuels Avgas (gal) | Foam Agents 6-Percent Solution Manufacturer B (gal) | Foam Agents 6-Percent Solution Manufacturer A (gal) | Fire Control Time (sec) | Fire Extinguishing Time (sec) | Fire Burn-Back Time (sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 44 | 400 | 4000 | 8000 | 0.05 | 1200 | - | - | - | 353 | 49 | 53 | 45 |
| 45 | 400 | 4000 | 8000 | 0.05 | 1200 | - | - | 380 | - | 48 | 57 | 55 |
| 46 | 800 | 4000 | 5333 | 0.15 | 1200 | - | - | - | 426 | 26 | 32 | 25 |
| 47 | 800 | 4000 | 5333 | 0.15 | 1200 | - | - | 426 | - | 23 | 32 | 39 |
| 48 | 800 | 4000 | 16000 | 0.05 | 1200 | - | - | - | 467 | 25 | 35 | 457 |
| 49 | 800 | 4000 | 16000 | 0.05 | 1200 | - | - | 600 | - | 36 | 45 | 521 |

the same as the fire area, for comparison with the experiments in which the area of foam application was larger than the fire area. These data show that at a solution application rate of 0.15 gal/min/sq ft, the variation in solution application density for all experiments varied by 0.014 gal per sq ft and for an application rate of 0.05 gal/sq ft it was 0.019 gal/sq ft. An evaluation of these data tend to indicate that at solution application rates between 0.10 and 0.12 gal/min/sq ft, the foam solution application density on areas larger than the fire area would provide foam solution densities closely approaching those obtained for fires in which the fire area was the same as the area of foam application. These solution application rates are in nominal conformance with the values reported in Reference 9 for different formulations of AFFF liquids and foam-dispensing nozzles.

## SUMMARY OF RESULTS

The results obtained from the laboratory tests and the full-scale fire-modeling experiments using AFFF agents at different solution application rates on JP-4, JP-5 and avgas fuel fires are:

1. Manufacturer A's and Manufacturer B's AFFF liquid concentrate mixed in a ratio of 50:50 and subjected to accelerated aging tests produced sediment in excess of 0.25 percent (maximum allowable) by volume. All other mixtures of these agents yielded sediment of 0.25 percent by volume or less.

2. When Manufacturer A's and Manufacturer B's AFFF agents were mixed independently with one brand of 6-percent type protein foam liquid concentrate and subjected to accelerated aging, the sediment formed was below 0.25 percent (maximum alowable) by volume.

3. The stability of AFFF on the surface of aqueous solutions of methanol and on the surface of methanol/fuel mixtures decreased as the concentration of the alcohol increased.

4. The quality of Manufacturer A's and Manufacturer B's AFFF in terms of the expansion ratio and 25-percent solution drainage time produced by Foam Nozzles A and B exceeded the minimum requirements established in References 3 and 8.

5. The firefighting effectiveness of the two AFFF agents was determined to be a function of the configuration of the fire test bed, the foam solution application rate, the type of fuel and the foam quality.

6. Flame-wicking was evident with both Manufacturer A's and Manufacturer B's AFFF on JP-4 and avgas fuel fires. However, the extent of flame-wicking appeared to be a function of the test bed configuration and the method of foam application in terms of the foam/fuel turbulation as well as of the foam quality.

7. Water nozzle discharges of 6-percent solutions of the AFFF agents with estimated foam expansion ratios of less than 2:1 and 25-percent solution drainage times of less than 2 minutes gave progressive fire control and extinguishment of JP-4 fuel fires at solution applications rates of 0.035, 0.05 and 0.10 gal/min/sq ft.

8. The times to control and extinguish different size segments of a large JP-4 fuel fire indicated that at a solution application rate of 0.10 gal/min/sq ft both AFFF's achieved control and extinguishment of the required fire segment. However, when the foam solution application rate was reduced to 0.05-gal/min/sq ft, Manufacturer A's agent was able to control but not extinguish the fire segment, while Manufacturer B's agent was below the critical solution application rate required for either control or extinguishment.

9. The effect of two points of foam discharge over a single point, within the range of the nozzle, was to decrease the fire control and extinguishing times using Manufacturer A's AFFF agent while Manufacturer B's agent showed no significant differences in these factors.

10. No visible breakdown in foam structure was noted when protein foam and AFFF were dispensed from separate nozzles either sequentially or in combination on large free-burning JP-4 fuel fires.

11. AFFF dispensed at solution application rates of 0.10 and 0.12 gal/min/sq ft over defined areas larger than the actual fire area provided reasonably uniform foam coverage and blanket depth which gave fire control and extinguishing times closely approximating those in which the fire area was the same as the area of foam application.

## CONCLUSIONS

Based upon the results of the laboratory tests and full-scale fire-modeling experiments, it is concluded that:

1. In aircraft fire/rescue missions, mixtures of Manufacturer A's and Manufacturer B's AFFF agents and independent mixtures of these agents with protein-type foam should be avoided except in extreme emergencies.

2. Fires involving aqueous solutions of methanol and methanol/fuel mixtures may require higher foam solution application rates for control and extinguishment as the concentration of the alcohol increases in the mixture.

3. Water nozzle discharge of 6-percent solutions of AFFF agents are effective in the control and extinguishment of aircraft fuel fires.

4. To effectively secure a segment of a large free-burning pool fire using AFFF, the minimum solution application rate on that area should be 0.10 gal/min/sq ft.

5. A reduction in the fire control and extinguishing times may result when AFFF is discharged from two separate points around a free-burning pool fire over that obtained at the same solution rate from a single point of discharge and the order of magnitude of this reduction is a function of the particular agent employed.

6. AFFF and protein foams are mutually compatible when they are dispensed from separate nozzles, either sequentially or in combination on JP-4 fuel fires.

7. The firefighting effectiveness of the AFFF agents can be estimated from tests in which the area of fcam application is larger than the actual fire area.

# APPENDIX A

## METHOD FOR DETERMINING THE FOAM EXPANSION RATIO

## OF AGED MIXTURES OF FOAM LIQUID CONCENTRATES

### Objective.

The objective of the test is to determine the foam expansion ratio of mixtures of foam liquid concentrates subjected to the accelerated aging test of Federal Specification O-F-555c under 4, Quality Assurance Provisions; 4.7.7.2 high-temperature stability 149°F (65°C).

### Test Procedure.

A 6-percent solution of the aged foam liquid is prepared by mixing six parts of the concentrate with 94 parts of distilled water at 70°F ±2°F. Two-hundred milliliters (ml) of this solution are poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 revolutions per minute (r/min) for exactly 2 minutes. During the mixing process, the bowl is made to rotate approximately one revolution per second (r/s).

After mixing, the volume of the foam is determined from the calibrations on the side of the mixing bowl.

## APPENDIX B

## EFFECT OF POLAR SOLVENTS ON AFFF

It is known that the AFFF agents as a class show a very low order of stability toward polar solvents. However, an estimate of the stability of AFFF foam may be determined by employing the following procedure:

Objective.

The objective of the test is to determine the maximum concentration of a methanol-water mixture which will permit an AFFF to remain on the surface for a period of 3 minutes.

Test Procedure.

A sample of the experimental foam solution is prepared by mixing six parts of foam liquid concentrate with 94 parts by volume of fresh water at 70° ± 2°F. Two hundred milliliters (ml) of this solution are poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 revolutions per minute r/min for exactly 2 minutes. During the mixing process, the bowl is made to rotate at approximately 1 revolution per second (r/s).

After mixing, the foam is immediately poured onto the surface of 600 ml of the test polar-solvent solution contained in a 6-inch-diameter crystallizing dish and the foam screeded-off level with the rim.

The stability of the foam is measured in terms of the elapsed time after the foam is screeded-off level with the rim of the dish to the time any portion of the liquid surface is exposed as a consequence of foam decomposition.

## APPENDIX C

### LABORATORY FOAM-POWDER COMPATIBILITY TEST

The test method is a modification of that required in Reference 3 to determine the compatibility between Purple-K powder and protein foam and is concerned primarily with the addition of the important parameter of fuel to the system. Combinations of foams and dry-chemical powders, meeting the requirements of the modified test, have shown an acceptable degree of compatibility in terms of foam-blanket stability and depth in full-scale fire-modeling experiments.

Test Procedure.

A sample of the experimental foam solution is prepared by mixing six parts of the foam liquid concentrate with 94 parts by volume of fresh water at 70° $\pm$2°F. Two-hundred milliliters (ml) of this solution are poured into the large bowl of a kitchen mixer (Sunbeam Mixmaster Model 12C or equivalent) and beaten at a speed of 870 revolutions per minute (r/m) for exactly 2 minutes. During the mixing process, the bowl is made to rotate at approximately 1 revolution per second (r/s). At the end of the 2-minutes foam-mixing cycle and with the mixer running, a 10-gram (g) $\pm$0.1 g sample of the test powder is sprinkled onto the surface of the foam in the bowl and allowed to mix for an additional 30 seconds after which a 15-milliliter sample of the test fuel, such as JP-4, is added and the mixing continued for another 30 seconds. The foam mixture remaining in the bowl is removed with the aid of a spatula into the standard foam container (Reference 4, Foam Fire Equipment Standards) and screeded-off level with the rim.

The pan is then placed on a stand having a slope of 1-inch in 12 inches toward the front and constructed so that the top of the pan and the foam surface is 2-3/8 inches below a radiating metal surface. The heat source consists of a 1000-watt electrical hotplate with a 7-inch-diameter face (Edwin L. Wiegand Company, Pittsburgh, Pennsylvania, Model ROPH-100 or equivalent) mounted upside down over a 6 1/2-inch-diameter hole in a 1/2-inch thick piece of transite. The temperature of the hotplate face is maintained at 1000°F by varying the current input with a Variac transformer. To determine this temperature, it is convenient to use a thermocouple embedded in the hotplate. As the pan containing the foam is inserted, a sheet of transite 8 inches square and 1/2-inch thick is placed beneath the pan to insulate it from the hot stand.

A 100-ml graduated cylinder is placed under the draw-off tube of the foam container, and the liquid draining from the foam is measured at 30-second intervals. From these data the time required to collect 25 ml of solution is determined.

The results of experiments performed in accordance with this modified procedure using a variety of foam and dry-chemical agents indicated that if the time required to collect 25 ml of foam solution was 2.0 minutes or more, an acceptable degree of compatibility would be obtained under conditions involving a high degree of turbulence of the burning fuel, foam, and dry-chemical powder.

## APPENDIX D

### DEFINITION OF FIRE PREBURN, CONTROL, AND EXTINGUISHING TIMES

Figure D-1 shows the location of the heat sensors (radiometers) at the edge of the fire area from which data were obtained to draw the profiles in Figure D-2. The connotation of the terms preburn time and fire control time are indicated in Figure D-2, where heat flux is plotted as a function of time after fuel ignition. The profiles in Figure D-2 show the rather gradual rise in radiation intensity after fuel ignition until a maximum is reached which marks the start of the fire preburn time. After a preburn of 30 seconds at maximum intensity, foam is applied and time from the start of foam application to the time the heat flux is reduced to 0.2 Btu/ft$^2$-second is considered to be the fire control time.

The fire extinguishing time is the total elapsed time from the start of foam application until the foam application ceases after all fire areas have been extinguished with the exception of the three-dimensional fire in the center of the fire pit.

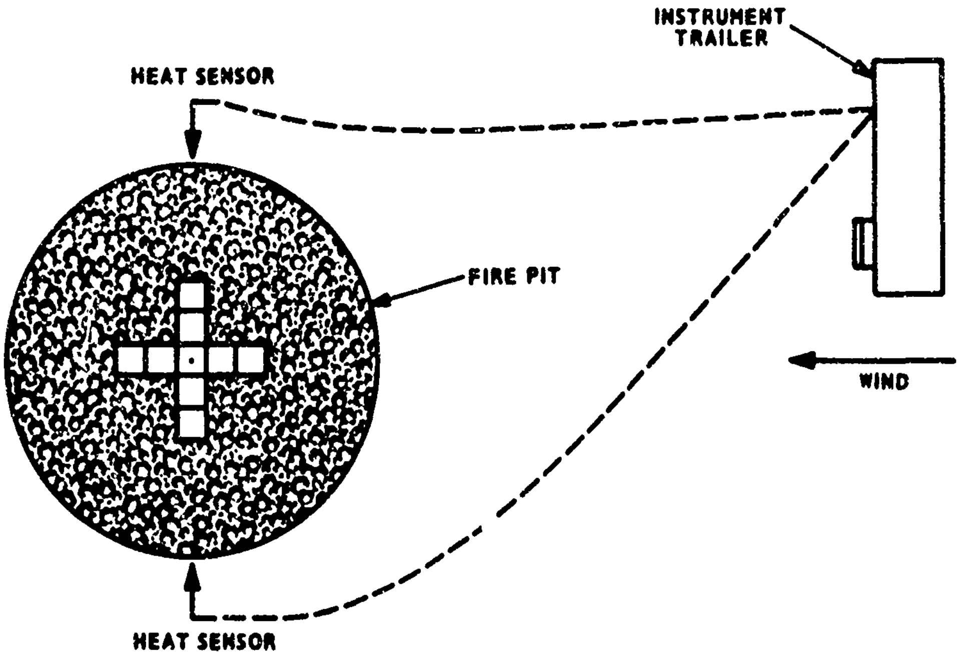


FIGURE D-1. INSTRUMENTATION FOR TESTS

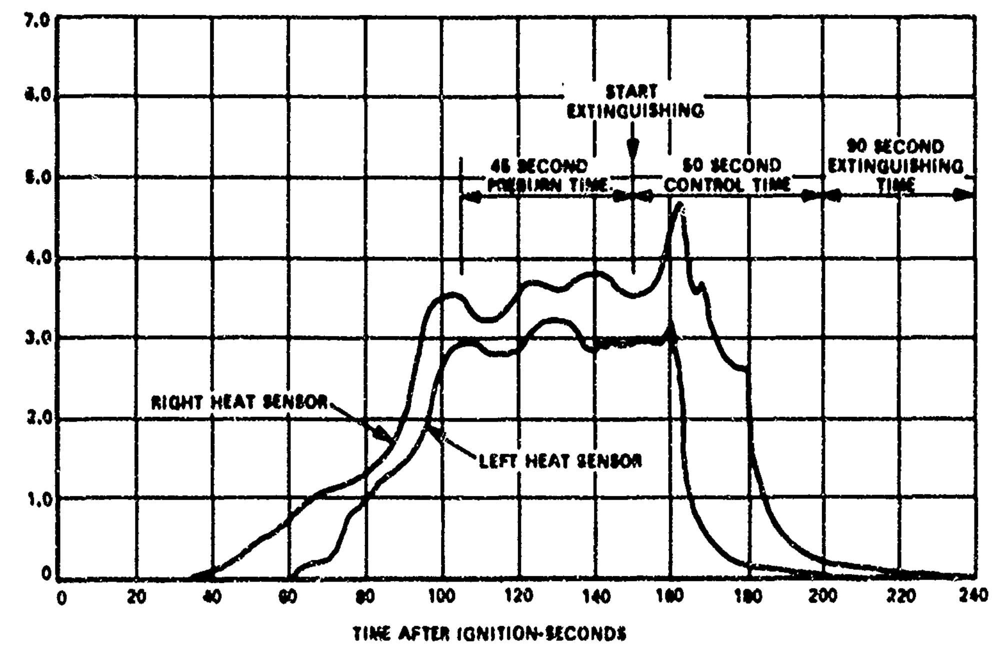


FIGURE D-2. TYPICAL TEST DATA SHOWING THE FIRE PREBURN TIME AND THE FIRE CONTROL AND EXTINGUISHING TIMES

# APPENDIX E

## PHOTOGRAPHIC TEST PLAN

Each full-scale outdoor fire-modeling experiment was monitored by two instrumentation cameras exposing 16-mm color film at 24 frames per second from fixed elevated positions strategically located around the fire test bed. One of these cameras had a remotely controlled clock in its line of sight with a 24-inch black and white dial graduated in minutes and seconds. Each of the cameras was manned by one photographer. The experiments required the instrumentation cameras to start operating 0.5 minutes prior to fuel ignition and to continue during the entire time required to obtain fire control and extinguishment and for a minimum period of 4 minutes thereafter. The estimated average film-running time of each camera during each test was 6 minutes.

A third motion picture camera exposing 16-mm color film at 24 frames per second was operated by one photographer from various positions around the fire test bed selected at his discretion.

One still picture photographer shot a maximum of six different photographs marking critical events before, during, and after each full-scale fire-modeling experiment. The photographs were printed on 8- by 10-inch glossy black and white stock.

## APPENDIX F

## ELECTRONIC FIRE-MONITORING EQUIPMENT

The instrumentation employed for the required parametic measurements consisted of radiometers and cameras. Recording instruments consisted of two potentiometer recorders, Dynamaster Model No. 960 manufactured by the Bristol Company, with two pens each and equipped with event markers which were manually actuated when foam was discharged.

Four heat flux transducers manufactured by Heat Technology Laboratory, Inc., Model GRW20-64P-SP, were mounted on metal stands and positioned around the fire pool. These radiometers measured the radiant heat flux and were rated at $10 \pm 1.5$ millivolts (mv) at 15 $Btu/ft^2$-sec. The angle of view was 120 degrees. Each unit was provided with a calibration curve by the manufacturer. Cooling water was supplied to each unit at the rate of 0.1 gal/min from a pressurized reservoir located at the base of each stand. Provision was made for gaseous (nitrogen) purging of the radiometer window which allowed measurements to be made in the sooty and contaminating fire environment without affecting accuracy by reducing the window transmissivity.

APPENDIX G

REFERENCES

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